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Radian Corp., Austin, TX

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ENVIRONMENTAL ASSESSMENT:
SOURCE TEST AND EVALUATION REPORT
RILEY GAS PRODUCER

by:

M.R. Fuchs, R.A. Magee, and P.M. Jeans

RADIAN CORPORATION
8501 MoPac Blvd.
Austin, Texas 78766

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EPA Project Officer: William J. Rhodes
Advanced Processes Branch
Industrial Environmental Research Laboratory
Research Triangle Park, NC 27711

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

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The report gives results of a Source Test and Evaluation (STE) of the lignite-fueled Riley Gas Producer as part of EPA's program to define and evaluate the environmental effects of low-Btu gasification. (NOTE: In December 1979, the Gas Producer, fueled by North Dakota (Indianhead) lignite, was tested at Riley Stoker Corp.'s research center in Worcester, MA, sponsored jointly by Riley Stoker and American Natural Service Co. of Detroit, MI.) The STE involved characterization of all inputs and outputs of the Gas Producer. Material balances were also developed. The output streams included the product gas, ash pan water, cyclone dust, and gasifier ash. The results indicate that all output streams have some potential for environmental concern, as either fugitive emissions (product gas) or discharge streams (dust, ash, ash pan water). Analyses of the leachates of the gasifier ash and cyclone dust showed that they were nonhazardous according to Resource Conservation and Recovery Act (RCRA) protocol and standards.

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ABSTRACT

In December 1979, Riley Stoker Corporation conducted a test of the Riley Gas Producer fueled by North Dakota (Indianhead) lignite. The test, which was held at Riley Stoker's research center in Worcester, Massachusetts, was sponsored jointly by Riley Stoker and American Natural Service Company of Detroit, Michigan. Radian Corporation performed a Source Test and Evaluation (STE) of the Riley Gas Producer as part of EPA's program to define and evaluate the environmental effects of low-Btu gasification. The results of the STE are presented in this report.

The Source Test and Evaluation involved characterization of all inputs and outputs of the Riley Gas Producer. Material balances were also developed. The output streams included the product gas, ash pan water, cyclone dust and gasifier ash. The results indicate that all of the output streams have some potential for environmental concern, either as fugitive emissions (product gas) or as discharge streams (dust, ash, ash pan water). Analyses of the leachates of the gasifier ash and cyclone dust showed that they were nonhazardous according to Resource Conservation and Recovery Act protocol and standards.

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SECTION 1

INTRODUCTION AND SUMMARY

Radian Corporation is under contract to the Environmental Protection Agency to perform a comprehensive environmental assessment of low- and medium-Btu coal gasification. This program includes the performance of Source Tests and Evaluations (STEs) to gather data for the assessment of viable low- and medium-Btu gasification systems.

This report, a Source Test and Evaluation Report (STER), presents the findings of an environmental assessment of the Riley Gas Producer. Riley Stoker Corporation, the Riley Gas Producer licensor, operates a commercial scale pilot plant at its research center in Worcester, Massachusetts. The test program, which was commissioned by American Natural Service Company (ANSC) of Detroit, Michigan, was conducted in December 1979.

1.1 Test Overview

The STE was designed to collect data pertinent to the environmental assessment of the Riley Gas Producer. For the most practical application of the results, testing was performed under "steady-state" operating conditions. The discharge and process streams of the gasification process were characterized to determine the potential environmental impact of each. Four streams were characterized:

- Product Gas
- Gasifier Ash
- Cyclone Dust
- Ash Pan Water

The product gas was separated into two fractions at 115°C (240°F) by the sampling procedure. The separation allows the characterization of the aerosols and vapors of the product gas which are the most likely source of fugitive emissions. The separation was achieved by collecting the aerosol phase of the product gas in an electrostatic precipitator operated at a temperature of 115°C (240°F). The aerosol phase consists of particulate matter and liquid tars and oils. The vapors of the product gas were collected downstream of the electrostatic precipitator in a condenser at a temperature of approximately 15°C (60°F) followed by an organics adsorption resin for organic vapors collection or an impinger train for collection of vaporous trace elements, ammonia, or hydrogen cyanide.

The Riley Gas Producer is a modification of the Morgan Gas Producer developed in England in the early 1900's. Riley Stoker has purchased the licensing rights to the Morgan Gas Producer and has updated several design features (Ref. 1). The gasifier feedstock was North Dakota (Indianhead) lignite* supplied by ANSC.

The major findings of this program are summarized below:

- Leaching studies conducted on the gasifier ash and cyclone dust to determine the effects of solid waste disposal indicated that the materials are non-hazardous according to Resource Conservation and Recovery Act (RCRA) protocol and standards (Ref. 3).
- Health effects bioassay tests of the gasifier ash and cyclone dust solids and neutral leachates of the gasifier ash and cyclone dust indicated no adverse health effects; ecological bioassay results of neutral leachates of the gasifier ash and cyclone dust showed significant toxic effects.
- Approximately 53 percent of the sulfur found in the lignite feedstock was converted to reduced sulfur species in the product gas.
- Approximtely 26 percent of the nitrogen found in the lignite feedstock was converted to reduced nitrogen species in the product gas.
- Enclosing and pressurizing the coal bin and using a nitrogen purge on the gasifier pokehole significantly reduce fugitive emissions from these sources.

1.2 Results

1.2.1 Gasifier Performance

The North Dakota (Indianhead) lignite gasifier feedstock for the 24-hour test period had an average sulfur concentration of 0.44g/10^6 J(1.02 lb S/10^6 Btu). Approximately 53 percent of the sulfur being fed to the gasifier was converted to reduced sulfur species in the product gas. If 100% of the reduced sulfur species in the product gas were converted to SO_2 during combustion, the resulting SO_2 emission level would be 0.49g/10^6 J (1.10 lb SO_2/10^6 Btu) based upon the heat content of the lignite.

---

*In December 1978, Radian Corporation characterized a Wellman-Galusha gasification system using North Dakota (Indianhead) lignite supplied by ANSC. Radian characterized a test run of the system at the Bureau of Mines' Twin Cities Metallurgy Research Center at the Fort Snelling site (Ref. 2).

The average ammonia concentration of the product gas was 7.8×10^5 $\mu g/Nm^3$ and the average hydrogen cyanide concentration was 1.8×10^5 $\mu g/Nm^3$. These species contained approximately 26 percent of the nitrogen in the lignite feedstock.

The particulate loading of the product gas stream was 4.76×10^5 $\mu g/Nm^3$ downstream of the cyclone. The particulate was assumed to be of the same composition as the cyclone dust, and the cyclone dust ash content (39.93%) was used for calculations to determine the particulate emissions from combustion. Basing the adjusted particulate loading upon the heat content of the lignite feedstock, the particulate emissions after combustion would be 0.026g particulate/10^6 J (0.06 lb particulate/10^6 Btu). This emission estimate does not consider particulate that may result from incomplete combustion of tars and oils.

1.2.2 Fugitive Emissions

Fugitive emissions of hydrocarbons were measured in the area of the gasifier by several methods. Hydrocarbon concentrations were less than 6.5×10^2 $\mu g/Nm^3$ (<1 ppm as CH_4). Hydrocarbons were also measured in the off-gases of the nitrogen-pressurized coal bin. The concentrations were 3.2×10^3 $\mu g/Nm^3$ to 3.9×10^3 $\mu g/Nm^3$ (5-6 ppm as CH_4). Readings of two carbon monoxide monitors maintained by Riley Stoker were recorded during the sampling period. The maximum recorded carbon monoxide concentration was 2.7×10^4 $\mu g/Nm^3$ (24 ppm) with readings generally well below this value. The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for carbon monoxide is 5.7×10^4 $\mu g/Nm^3$ (50 ppm) (Ref. 4). There is no OSHA regulation for hydrocarbons as a compound class. Propane is the lightest hydrocarbon regulated by OSHA and has a PEL of 1.8×10^6 $\mu g/Nm^3$ (1000 ppm).

Radian Corporation has performed STEs for a Chapman low-Btu gasifier with a bituminous coal feedstock and a Wellman-Galusha low-Btu gasifier with an anthracite coal feedstock. The Chapman STER (Ref. 5) presents results for coal feeder vent gases for hydrocarbons ($<C_7$) of 2.5×10^6 $\mu g/Nm^3$ and carbon monoxide of 2×10^7 $\mu g/Nm^3$. The coal hopper gases at the Wellman-Galusha facility (anthracite) were reported in the STER (Ref. 6) as 1.4×10^6 $\mu g/Nm^3$ methane and 2.7×10^8 $\mu g/Nm^3$ carbon monoxide. Related values measured at the Riley Gas Producer are several orders of magnitude less. These data demonstrate the relative reduction of fugitive emissions achieved by the controls employed on the coal bin at the Riley Gas Producer.

1.2.3 Trace Elements

Trace elements enter the gasification process with the lignite feedstock and are subjected to the high temperatures of the process. Many elements, especially the more volatile ones, undergo volatilization in the hot areas of the system and may either remain a vapor in the product gas, condense homogeneously or condense upon aerosol particles. Other elements are chemically transformed into gaseous species and are emitted in the product gas. Most trace elements remain in the coal solids and are emitted in the gasifier ash. Even though the majority of most elements are emitted with the solid waste streams, RCRA extraction procedure analysis results in the classification of these solids as non-hazardous.

Minor and trace elements can then be grouped according to the mechanism by which each is discharged. The elements primarily in the product gas can be considered highly volatile or transformed into gaseous compounds. Moderately volatile elements are predominantly in the cyclone dust or product gas particulate and can be evaluated on the basis of the volatilization and recondensation. Elements discharged predominantly in the gasifier ash can be considered to be non-volatile elements.

For this STE, an element was considered to be highly volatile if 25 percent or more of its total mass was found in the vapors portion of the product gas. These highly volatile elements were:

bromine
cesium
chlorine
fluorine
gallium
iodine
mercury
selenium
silicon
sulfur
tellurium

An element was classified as moderately volatile if 25 percent or more of its total mass was found in the cyclone dust and aerosols portion of the product gas. These elements were:

antimony
arsenic
chromium
germanium
lead
tin
zinc

The following elements will require additional data to characterize their behavior definitively:

beryllium
bismuth
cadmium
dysprosium
erbium
europium
gold
holmium
iridium
neodymium
osmium
palladium
platinum
praeseodymium
rhenium
rhodium
ruthenium
silver
tantalum
terbium
thallium
thulium
uranium
ytterbium

Figure 1-1 graphically presents the elemental distributions in the discharge streams. The elements are listed in the order of increasing elemental boiling points. In general, as the elemental boiling points increase, the predominance of elemental distribution shifts from the product gas to the gasifier ash. Although a general trend is evident, there is no direct correlation between elemental boiling point and distribution. The distribution of individual elements in the system is dependent not only on elemental boiling point, but also on much more complex properties. These may include chemical reactions in the gasifier, the volatility of compounds containing the elements and solubility of compounds in the tars and oils.

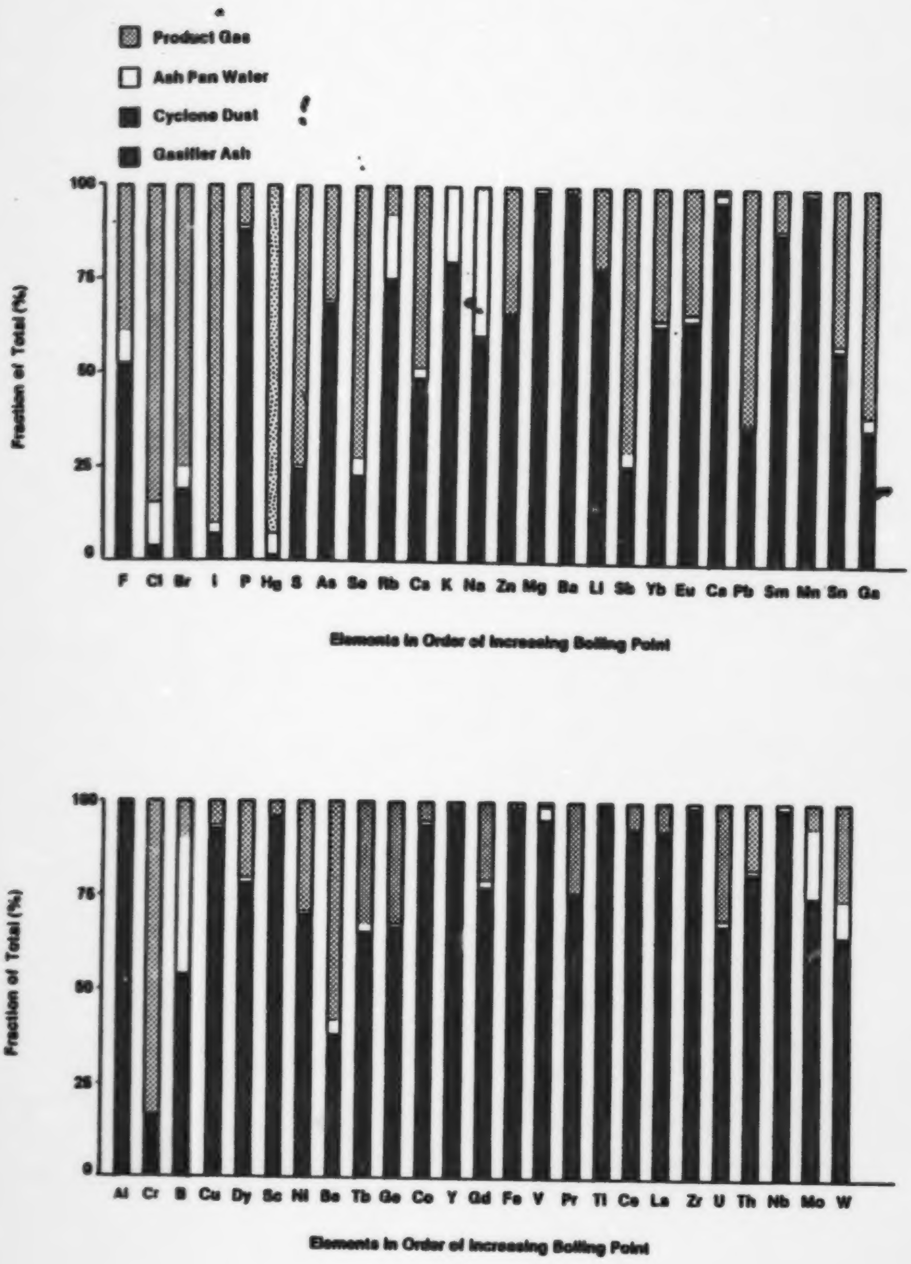

Figure 1-1. Stream Elemental Distributions as Percentage of Combined Discharge Streams

SECTION 2

PLANT DESCRIPTION

The Riley Gas Producer is a full-scale commercial size gasification facility located at the Riley Research and Development Center in Worcester, Massachusetts. The facility was constructed by Riley Stoker Corporation to conduct performance tests of the gasifier on various coals. In December of 1979, American Natural Service Company (ANSC) commissioned a test program of the Riley Gas Producer using North Dakota (Indianhead) lignite. Radian Corporation, as part of an EPA program to environmentally assess low-Btu coal gasification, conducted a STE program at the Riley Gas Producer.

In 1973 Riley Stoker Corporation obtained the rights to the Morgan Gas Producer, originally designed in the early 1900's. Although the Riley Gas Producer utilizes the basic design of the old Morgan Gas Producer, Riley Stoker has upgraded the mechanical construction of the gasifier and modified some portions of the system (Ref. 1).

2.1 Process Description

The following sections briefly describe the Riley Gas Producer facility and operations during the test period. Process operations of the gasifier are explained in more detail in Appendix A. Figure 2-1 is a schematic of the Riley Gas Producer facility showing the sampling locations.

2.1.2 Coal Handling

The lignite feedstock was screened at the mine site to a size of 1/2 to 2 inches and delivered to a site (not the gasification facility) in Worcester where it was stored in open piles. The coal was delivered as needed to the gasification facility in dump trucks, unloaded into an underground hopper, and conveyed to a coal bin located above the gasifier.

From the coal bin, the lignite was fed by gravity into a lock hopper system controlled by valves above and below the lock hopper. A continuous coal feeder supplied lignite to the gasifier and evenly distributed the lignite over the coal bed during each revolution of the reactor.

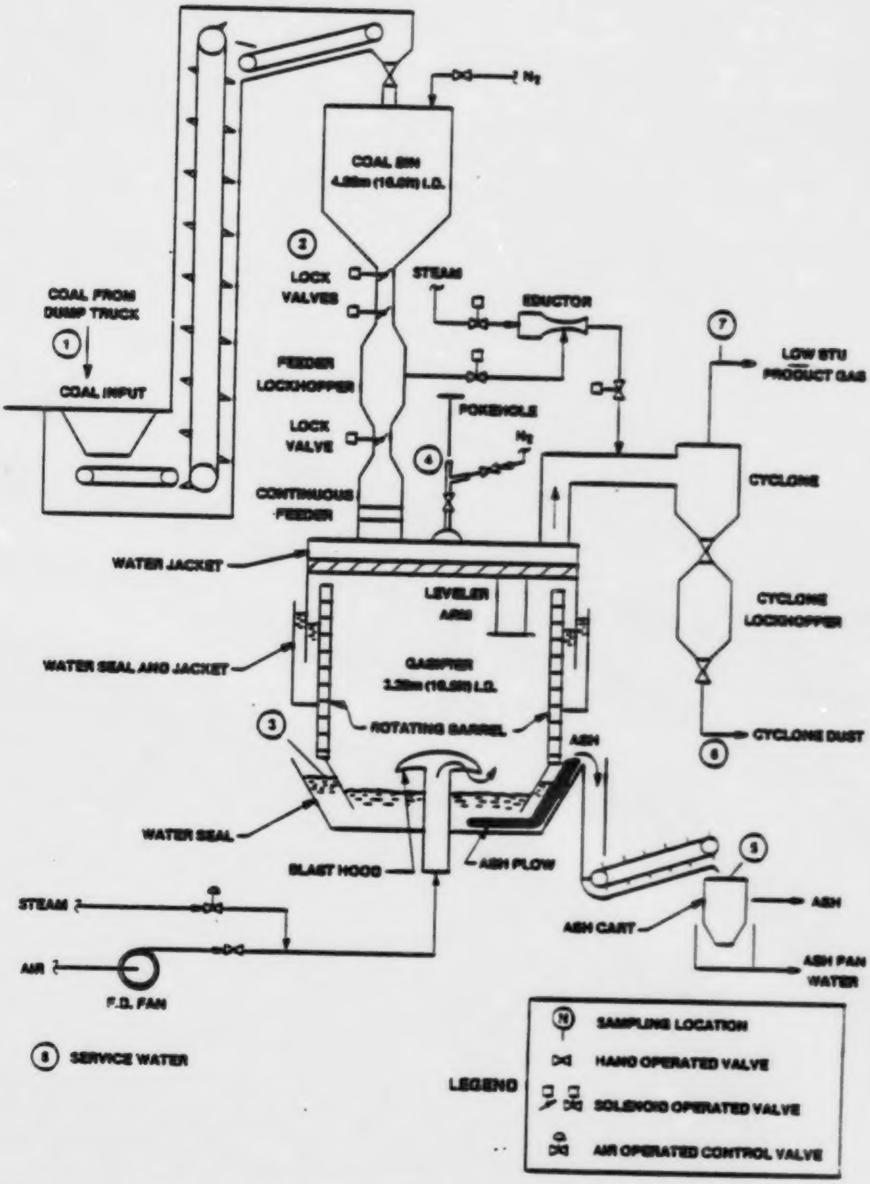
COAL BIN
4.88m (16.0ft) I.D.
N₂
②
LOCK VALVES
STEAM
EDUCTOR
COAL FROM DUMP TRUCK
①
COAL INPUT
FEEDER LOCKHOPPER
⑦
LOW BTU PRODUCT GAS
LOCK VALVE
POKEHOLE
N₂
④
CONTINUOUS FEEDER
CYCLONE
WATER JACKET
LEVELER ARM
CYCLONE LOCKHOPPER
WATER SEAL AND JACKET
GASIFIER
3.20m (10.5ft) I.D.
③
ROTATING BARREL
ASH
CYCLONE DUST
⑥
WATER SEAL
BLAST HOOD
ASH PLOW
⑤
STEAM
ASH
ASH CART
AIR
F.D. FAN
ASH PAN WATER
⑧ SERVICE WATER
LEGEND
Ⓝ SAMPLING LOCATION
HAND OPERATED VALVE
SOLENOID OPERATED VALVE
AIR OPERATED CONTROL VALVE

Figure 2-1. Schematic of Riley Gas Producer

2.1.3 Gasifier

The gasifier is an atmospheric pressure, air-blown, thin fixed-bed design in which the barrel of the reactor constantly rotates, one revolution per six and one-half minutes. Below the reactor is the ash pan which retains the gasifier ash and water to form the pressure seal. Moist air is blown up through the reactor from a blast shield in the ash bed.

As coal is fed to the gasifier, it contacts the upward moving hot product gas which volatilizes many hydrocarbons in the coal. As the lignite nears the oxidation zone of the coal bed, the carbon in the coal reacts with water in the blast air to form hydrogen and carbon monoxide. The resulting product gas has a lower heating value (LHV) of approximately 5.8×10^6 joules per normal cubic meter (dry) [160 Btu per standard cubic foot (dry)]. In the oxidation zone, coal is combusted by the oxygen present in the blast air to form heat for the gasification reactions.

Ash resulting from the combustion of coal is removed from the ash pan by affixing a helical plow to the stationary ash pan. As the reactor rotates, ash is forced from the ash pan by the plow and conveyed to a hopper for disposal.

Service water is continuously sprayed onto the reactor for cooling and then contained in the ash pan. Effluent ash pan water is discharged to the sewer.

Particulates are removed from the product gas by a hot cyclone equipped with a lockhopper system for removal of particulates. From the cyclone, the product gas is directed to a burner where the total production of low-Btu gas is combusted.

2.2 Plant Operation

The gasifier test plan called for a three day start-up period to achieve "steady-state" conditions and to develop the maximum lignite feed rate. [The goal was 1500 grams per second (12000 lb/hr).] After the start-up period, the gasifier was to be operated at "steady-state" conditions for five days. Because of a series of operational problems, the gasifier test period was twelve days with one day of "steady-state" operation at a coal feed rate of 970 g/s (7700 lb/hr), the maximum rate achieved with consistent operation. Radian's sampling effort was performed during the one-day peak performance period of the gasifier, roughly 10 a.m. December 13 through 10 a.m. December 14.

2.3 Process Flow Rates and Mass Balances

Mass balances have been prepared using the process and sampling data collected during the STE. The mass balances have been derived to indicate the accuracy of measurement techniques and reliability of results as well as to insure a complete characterization of system operation.

Process data were gathered manually by Radian personnel as part of EPA's participation in the program. Additionally, Riley had recorders for many process parameters. Flow rates and material balances have been determined using the manually recorded process data plus data generated by Radian during the sampling effort.

Material balances have been prepared based upon two sets of conditions. Material and component balances have been determined for the specific time of 4 a.m. December 14, using process and analytical data determined at this time. Closure of these balances was "forced" and represents the most probable conditions based upon engineering judgements. Table A-9 of Appendix A presents the overall material balance; Table A-10 of Appendix A presents the component material balance determined in conjunction with the overall material balance.

Another material balance was determined and presents average flow rates over the time period of 10 a.m. December 13 to 10 a.m. December 14. This material balance includes error limits, either empirical or judgement values, on flow rate and analytical measurements. Empirical error limits are derived from analytical results from either several samples or duplicate or more analyses of a single sample. Judgment values for error limits, used predominantly for flow rates, are based on experience with the measurement technique and observations of variability during the test period. As a result, the error limits indicate not only the variance of sampling and analytical techniques, but also the variability of the process and process material compositions and flow rates with time. All empirical error limits are one standard deviation. The purpose of this material balance is to reflect the average process conditions over the 24-hour period and the degree of reliability and variability of those values. The total material balance is presented in Table 2-1 along with the major component material balances. The flow rate values presented in the material balance in Table 2-1 were used in trace element distributions and in other calculations requiring process flow rates. The range of "Out/In Limits" indicates the closure of the balance. If the limits pass through one, the balance is considered closed within the predictable variance of the measurement techniques and process variability.

TABLE 2-1. GASIFICATION PROCESS MATERIAL BALANCE WITH ERROR LIMITS

	TOTAL		ASH			CARBON			NITROGEN			OXYGEN		
	g/s	Error Limit %	g/s	Conc. %	Error Limit %	g/s	Conc. %	Error Limit %	g/s	Conc. %	Error Limit %	g/s	Conc. %	Error Limit %
INLET STREAMS:														
Coal	670±100	15*	81±14	12.1	18.2	420±45	63.3	2.5	6.7±0.8	1.0	3.9	120±14	17.9	7.2
Air	1200±240	20*							940±190	78.1	—	350±30	20.9	--
Moisture (coal)	330±9	2.7										290±8	88.9	—
Moisture (BST)	350±88	25*										310±78	88.9	--
Service Water	2200±440	20*										2000±400	88.9	--
Total	4800±880		81±14			420±45			950±190			3000±550		
OUTLET STREAMS:														
Product Gas (dry)	2300±230	10*	1.1±0.2	0.05	20*	400±32	17.5	4.8	1200±94	52.0	4.8	640±50	27.8	4.8
Moisture (P.G.)	620±61	9.8										550±54	88.9	
Tars and Oils (P.G.)	21±4	20*	0.04	0.2	--	12±2	58.6	--	0.2±0.04	0.7	—	6.5±1.3	30.8	--
Cyclone Dust	4±1	20*	1.6±0.2	39.9	3.8	2.1±0.3	53.7	2.0	0.03	0.8	2.4	0.1±0.02	2.4	18.8
Gasifier Ash	75±30	40*	47±14	62.5	16.6	27±9	35.4	26.6	0.4±0.1	0.5	21.7		0	
Ash Pan Water	2200±440	20*										2000±400	88.9	
Total	5200±770		50±14			440±43			1200±94			3200±500		
Total Outlet Streams / Total Inlet Streams	1.08		0.62			1.05			1.26			1.24		
Out/In Limits	1.32 - 0.78		0.96 - 0.38			1.29 - 0.85			1.70 - 0.97			1.60 - 0.97		

(Continued)

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TABLE 2-1. Continued

	HYDROGEN			SULFUR			ARGON		
	g/s	Conc. %	Error Limit %	g/s	Conc. %	Error Limit %	g/s	Conc. %	Error Limit %
INLET STREAMS:									
Coal	29±3.2	4.3	4.6	7.4±4.3	1.10+	80.2			
Air							10.8±2	0.9	—
Moisture (coal)	37±11	11.1	—						
Moisture (BST)	39±10	11.1	—						
Service Water	240±48	11.1	—	0.008±0.00036					
Total	350±62			7.4±4.3			10.8±2		
OUTLET STREAMS:									
Product Gas (dry)	37±3	1.7	4.8	3.9±0.3	0.17	4.8	14±1	0.6	4.8
Moisture (P.G.)	69±7	11.1							
Tars and Oils (P.G)	1.8±0.4	8.4	—	0.07±0.01	0.33	—			
Cyclone Dust	0.06	1.5	2.0	0.07±0.01	1.7	4.2			
Gasifier Ash	0.4±0.1	0.6	26.2	1.2±0.3	1.6	5.5			
Ash Pan Water	240±48			1.1±0.4	0.05	53.4			
Total	349±58			6.3±1.0			14±1		
Total Outlet Streams / Total Inlet Streams	1.00			0.85			1.30		
Out/In Limits	1.4 - 0.71			2.21 - 0.42			1.70 - 1.02		

* Error limit based on judgment value. All other error limits are empirically derived and are one standard deviation (δ).

+ Value is average of sulfur values of 17 lignite samples.

SECTION 3

METHODS

Sampling and analytical methods are detailed in Appendices B and C and in "IERL-RTP Procedures Manual: Level I Environmental Assessment" (Ref. 7). The following are brief descriptions of the individual techniques and provide an overview of the sampling and analytical program.

3.1 Sampling Methods

Radian Corporation prepared a test plan detailing the sampling effort to be conducted over a 5-day period during steady-state operation of the gasifier. However, operation of the gasifier prevented implementation of the test plan as conceived and necessitated the performance of a single 24-hour continuous sampling effort. During the 24-hour sampling period, all parameters as listed in the test plan were addressed; however, many of the replicate samples were not collected as originally planned.

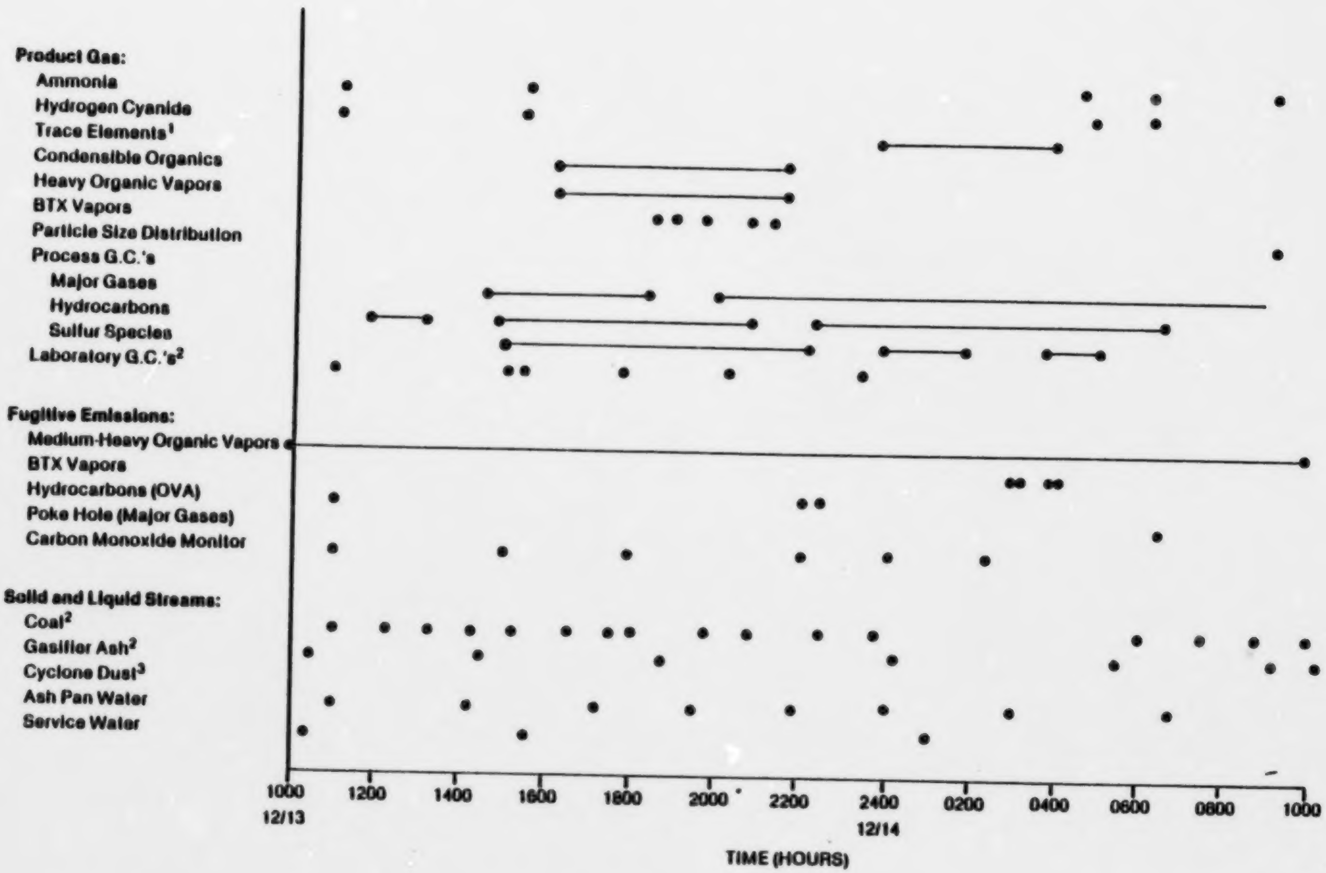
The sampling effort characterized the process and discharge streams of the gasification facility—product gas, gasifier ash, cyclone dust, and ash pan water—and the inlet streams—lignite and service water.

Appendix A discusses in detail the operation of the gasifier in the 2-week operational test period. Environmental and process characterization sampling was conducted during a 24-hour period, 10 a.m. December 13 through 10 a.m. December 14. Prior to this period, gasifier operation was considered atypical of normal production due to operating conditions or non-achievement of steady state operation. Figure 3-1 shows the samples collected from each stream and the time of collection.

Sampling was also conducted at the pokehole level of the gasifier to determine the concentration of fugitive emissions from the gasification process.

3.1.1 Product Gas Sampling

The product gas was sampled downstream of a hot cyclone used for particulate removal. Probe sampling was performed through a 4-inch gate valve, and gas samples for the process gas chromatographs were collected through a 2-inch gate valve just upstream of the larger valve.



[1] Acid/Base and Persulfate Impinger trains

[2] Other samples collected outside of 24-hour sampling period

[3] Samples received from Riley-Stoker

●——● extended or continuous sampling

Figure 3-1. Sampling Matrix for Riley Gas Producer

The sampling system consisted of a probe, electrostatic precipitator (ESP) and filter, gas collection devices, and the pumping and metering system. The probe was inserted through a packing gland mounted to the 4-inch valve to prevent leakage of product gas into the work area. The sample gas was drawn isokinetically through a gooseneck nozzle and through heat-traced stainless steel tubing to the ESP followed by a glass fiber filter. The ESP and filter were maintained at a temperature of 115°C (240°F) in an oven during sampling. After removal of particulate and aerosol tars and oils by the ESP and filter, gas phase constituents of interest were collected from the sample gas by one of two means. Trace metals, ammonia, and cyanide were collected in impinger trains and organics were collected in an organic module consisting of a condenser followed by XAD-2 resin. The pumping and metering system was downstream of the gas collection device and was used to draw the sample and to maintain a negative pressure within the glass impingers for sealing purposes.

The ESP was incorporated in the sampling system to remove aerosol condensed tars and oils from the sample gas. Aerosol tars and oils quickly foul conventional particulate collection devices such as filters or cyclones and create a considerable amount of system downtime.

The ESP operates by creating an electron wind between positively and negatively charged (10 KVDC) electrodes. Once removed from the gas stream, the viscous but liquid tars and oils with suspended particulates flow into a collection cup in the lower portion of the ESP. In previous tests, the ESP has been shown to be as much as 99% efficient in the removal of aerosol material. During this sampling effort, the ESP had a collection efficiency of 98%. A schematic of the ESP is presented in Figure 3-2.

The use of the ESP for sampling streams laden with tars and oils provides several types of samples for analysis of organics. The probe and ESP/filter collect aerosol organic material and the organic module downstream of the ESP/filter collects gas phase organics. For this program, aerosol organics and organic vapors that condense at 115°C (240°F) (ESP/filter temperature) were quantified as one sample by analyzing the material collected by the probe, ESP and filter. Gas phase organics were quantified in the material collected by the condenser at a temperature of 15°C (60°F) and the XAD-2 resin.

The product gas vapor phase organic sample was collected using the organic module of the Source Assessment Sampling System (SASS) (Ref. 7). The organic module was modified by mounting the resin canister on the side of the condenser instead of below. This modification prevented the condensate from flowing through the resin canister and moistening the resin.

Level 1 protocol requires a gas sample volume of 30 standard cubic meters (0°C, 1 atm). This value, however, is based upon sampling combustion products. Due to the high organic loading of the product gas stream, slightly less than 4 normal cubic meters (25°C, 1 atm) were sampled for characterization of vaporous organics.

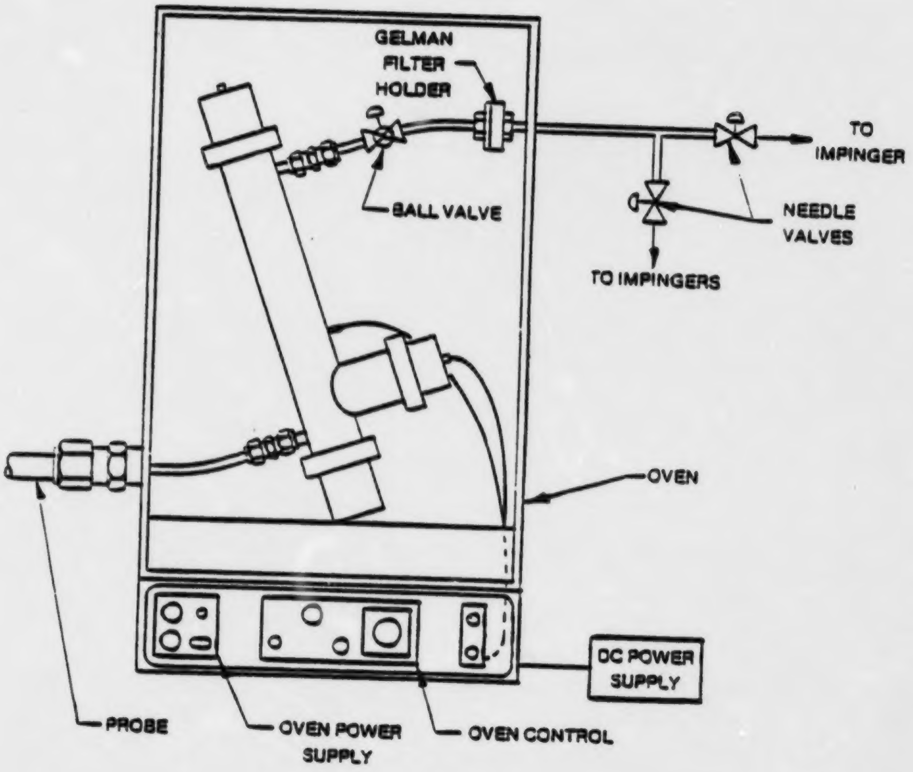

GELMAN
FILTER
HOLDER
TO
IMPINGER
BALL VALVE
NEEDLE
VALVES
TO IMPINGERS
OVEN
DC POWER
SUPPLY
PROBE
OVEN POWER
SUPPLY
OVEN CONTROL

Figure 3-2. Schematic of ESP

Gas phase trace elements in the product gas were collected from the ESP/filter exit gas in two different types of impinger trains. One type consisted of two Greenburg-Smith impingers containing a solution of $2M(NH_4)_2S_2O_8$ + $0.2M\ AgNO_3$. The other type consisted of two Greenburg-Smith impingers containing 10% nitric acid followed by two Greenburg-Smith impingers containing 10% sodium hydroxide.

The two impinger trains were run simultaneously to allow an accurate comparison of the collection efficiencies of the two systems. Simultaneous sampling was accomplished by dividing the sample gas line downstream of the ESP/filter into two streams for simultaneous collection by both impinger trains. Two pumping and metering systems were used to accomodate the system.

During the trace element sampling, a leak in the sampling system reduced the effective sampling volumes by a factor of 8.64 (see Appendix B). The resulting sample gas volumes were small enough that many trace element concentrations were near or below analytical detection limits. Therefore an accurate evaluation of the two trace element collection systems is not possible. In reviewing the data, however, it is apparent that more (and generally larger) analytical values are available from the $(NH_4)_2S_2O_8$-$AgNO_3$ collection system than from the acid/base collection system. For this reason, the $(NH_4)_2S_2O_8$-$AgNO_3$ results for trace elements are used in this report.

Ammonia and cyanide samples were collected from product gas using impinger systems. Ammonia was collected in two Greenburg-Smith impingers containing 5% sulfuric acid. Two Greenburg-Smith impingers containing 10% sodium hydroxide were used to collect hydrogen cyanide.

3.1.2 Solids Sampling

Dump trucks delivered lignite to the plant and dumped it into a pit. The lignite samples were collected in one-gallon polypropylene bags as the lignite fell from the truck into the pit. The bags were fully opened and passed through the falling lignite on a line parallel to the truck. Variations in particle size were apparent across the falling lignite stream. This sampling technique provided for the collection of a more representative sample by averaging the lignite size collected. One sample was collected from each dump truck load of lignite. The bags were sealed after collection of the samples and were returned to Radian for analysis.

Gasifier ash samples were collected during each ash removal or "plow". The ash was forced from the ash pan and conveyed to a hopper for dewatering and disposal. Samples were collected from the hopper. Samples for organic analysis were collected in glass bottles with Teflon -lined caps; samples for inorganics were collected in polyethylene bottles.

During the 2-week gasifier test period, no dust was removed from the cyclone. After the test period was completed, dust that had been collected in the cyclone was removed by Riley Stoker personnel. Samples of the cyclone dust were collected by Riley personnel in glass bottles with Teflon -lined caps and sent to Radian.

3.1.3 Liquids Sampling

Ash pan water samples were collected directly from the ash pan using the sample container. Samples for organic analyses were stored in amber glass bottles with Teflon -lined caps; samples for wastewater and trace element analyses were stored in polyethylene bottles. Service water samples were taken from a service water line at the gasifier and were stored in containers as described above for ash pan water.

3.1.4 Sample Preservation

There were no preservation procedures used for the solid samples except for sealing them in glass or plastic containers as discussed in Section 3.1.2.

Liquid samples for organic analyses were stored in amber glass bottles that were filled completely to exclude air, sealed with Teflon seals, and refrigerated. Samples for wastewater and trace element analyses were stored in polyethylene bottles. The preservation techniques for the wastewater and trace element parameters are listed in Table 3-1.

3.2 Analytical Methods

Laboratory analyses of the solid and liquid samples followed the matrix shown in Table 3-2. The samples joined by brackets in the analytical matrix were composited prior to the indicated analyses. The analytical techniques for water quality parameters are listed in Table 3-1. Descriptions of the analytical procedures are given in Appendix C.

3.2.1 Elemental Analysis

Analyses for 15 elements by inductively coupled argon plasma emission spectrometry (ICPES) and 5 elements by atomic absorption spectrophotometry (AAS) were performed in addition to spark source mass spectral analyses (SSMS). The analyses were performed on the following samples:

- Cyclone dust
- Gasifier ash
- Lignite
- Ash pan water
- Service water
- Ash pan carry-over water
- Product gas acid/base and persulfate impingers

The analytical techniques were compared to determine the feasibility of using ICPES for the screening of low-Btu gasification samples. ICPES requires that the sample be in a liquid form for analysis, i.e., solids must be

TABLE 3-1. PRESERVATION TECHNIQUES FOR WASTEWATER AND TRACE ELEMENT ANALYSIS

Parameter	Location	Analytical Method	Preservation Technique
pH	OS+	Corning Model 3D pH meter with combination electrode	None
Conductivity	OS	YSI Model 33 conductivity meter	None
Phosphate	Lab*	Colorimetric	H_2SO_4, pH<2, cool
Chloride	Lab	Colorimetric	Cool
Fluoride	Lab	Specific ion electrode	Cool
Sulfide	OS	Titrimetric	None
Nitrate	OS	Colorimetric	Cool
Cyanide	OS	Distillation/colorimetric	S=removed, NaOH, pH>12, cool
Thiocyanate	Lab	Extinction/colorimetric	S=removed, NaOH, pH>12, cool
Sulfate	Lab	Turbidimetric	Cool
Ammonia	OS	Distillation/titrimetric	H_2SO_4, pH<2, cool
COD	Lab	Reflux/titrimetric	H_2SO_4, pH<2, cool
BOD	Lab	Digestion/titrimetric	Cool
TOC	Lab	Dohrmann Model 54 TOC analyzer	H_2SO_4, pH<2, cool
TSS	Lab	Gravimetric	Cool
TDS	Lab	Gravimetric	Cool
Phenol	Lab	Distillation/colorimetric	H_3PO_4, pH<4, cool
Trace Metals	Lab	SSMS/AAS/ICP	HNO_3, pH<2

+On-site analysis

*Radian's Austin Laboratories

TABLE 3-2. ANALYTICAL MATRIX FOR RILEY GAS PRODUCER SAMPLES

Sample Log #	 Description	% H_2O	Ultimate/ Proximate	Sizing	Morphology	SSMS	AA-ICP	Water Quality	BTX	Organics: Screening	Organics: Detailed	Leaching	Bioassay	Radiation
RM-73	Lignite	X	X	X	X	X	X							X
RM-75	Lignite	X	X	X	X									
RM-76	Lignite	X	X	X	X									
RM-77	Lignite	X	X	X	X	X	X							X
RM-81	Lignite	X	X	X	X									
RM-82	Lignite	X	X	X	X									
RM-95	Gasifier Ash		X	X	X									
RM-98	Gasifier Ash		X	X	X									
RM-126	Gasifier Ash		X	X	X	X	X			X	X	X	X	X
RM-147	Gasifier Ash		X	X	X	X	X							
RM-149	Gasifier Ash		X	X	X									
RM-153	Cyclone Dust		X	X	X									
RM-154	Cyclone Dust		X	X	X	X	X			X	X	X	X	X
RM-157	P.G. Process GC ESP Tar		X											
RM-20	P.G. XAD-2 Resin													
RM-21	P.G. Organic Module Condensate									X	X			
RM-22	P.G. Organic Module CH_2Cl_2 Rinse													
RM-50	P.G. ESP Tar Solids					X	X			X				
RM-58	P.G. ESP CH_2Cl_2 Rinse													
RM-51	P.G. Probe and Nozzle Solids													
RM-56	P.G. Probe and Nozzle CH_2Cl_2 Rinse					X	X			X	X			
RM-63	P.G. ESP to Filter Catch--CH_2Cl_2 Rinse													
RM-2	P.G. ESP Backup Filter #1													
RM-57	P.G. ESP Backup Filter #2					X	X			X				
RM-24	P.G. Charcoal #1 - 1000 cc								X					
RM-25	P.G. Charcoal #2 - 2500 cc								X					
RM-43	Blank Charcoal Tube								X					
RM-31	P.G. Trace Metals 1st Acid Impinger					X	X							
RM-32	P.G. Trace Metals 2nd Acid Impinger					X	X							
RM-33	P.G. Trace Metals 1st Basic Impinger					X	X							
RM-34	P.G. Trace Metals 2nd Basic Impinger					X	X							
RM-36	P.G. Trace Metals 1st Persulfate Impinger					X	X							
RM-37	P.G. Trace Metals 2nd Persulfate Impinger					X	X							

(Continued)

TABLE 3-2. Continued

Log #	Sample Description	% H_2O	Ultimate/ Proximate	Sizing	Morphology	SSHS	AA- ICP	Water Quality	BTX	Organics Screening	Organics Detailed	Leaching	Bioassay	Radiation
RN-6	Ash Pan Water							X						
RN-18	Ash Pan Water					X	X	X		X				
RN-23	Ash Pan Water					X	X	X		X	X			
RN-49	Ash Pan Water					X	X	X		X				
RN-4	Ash Pan Carry Over Water					X	X							
RN-3	Service Water					X	X	X		X	X			
RN-1	Deionized Water Blank					X	X	X		X	X			
RN-7	P.G. Cyanide #1-1st Impinger				CN- and SCN-									
RN-8	P.G. Cyanide #1-2nd Impinger				CN- and SCN-									
RN-12	P.G. Cyanide #2-1st Impinger				CN- and SCN-									
RN-13	P.G. Cyanide #2-2nd Impinger				CN- and SCN-									
RN-34	P.G. Cyanide #3-1st Impinger				CN- and SCN-									
RN-40	P.G. Cyanide #3-2nd Impinger				CN- and SCN-									
RN-51	P.G. Cyanide #4-1st Impinger				CN- and SCN-									
RN-33	P.G. Cyanide #4-2nd Impinger				CN- and SCN-									
RN-10	P.G. Ammonia #1-1st Impinger				Ammonia									
RN-11	P.G. Ammonia #1-2nd Impinger				Ammonia									
RN-15	P.G. Ammonia #2-1st Impinger				Ammonia									
RN-16	P.G. Ammonia #2-2nd Impinger				Ammonia									
RN-41	P.G. Ammonia #3-1st Impinger				Ammonia									
RN-42	P.G. Ammonia #3-2nd Impinger				Ammonia									
RN-53	P.G. Ammonia #4-1st Impinger				Ammonia									
RN-54	P.G. Ammonia #4-2nd Impinger				Ammonia									
RN-39	F.E. Tenax									X				
RN-44	F.E. Charcoal 496 cc								X					
RN-45	F.E. Charcoal 3000 cc								X					

Log Numbers correspond to the sample log given in Appendix B
P.G.: Product Gas
F.E.: Fugitive Emissions

dissolved. SSMS can be run on either solid or liquid samples with little or no preparation. ICPES has a greater analytical dynamic range (10^6) than SSMS, thus enabling quantification of the higher concentration components not possible with SSMS. The lower detection limits of ICPES, however, can be limited because of dilution in the digestion process. Detection for the lanthanides and actinides using SSMS is far superior to that with ICPES.

3.2.2 Organic Screening Analysis

The organic screening analysis was performed according to the procedures given in Appendix C. A significant deviation from the established procedures was the use of diethyl ether as an additional extraction solvent following methylene chloride extraction. This was done to increase the extraction efficiency for highly polar organic compounds.

Organic screening analyses include the determination of total chromatographable organics (TCO) using a gas chromatograph technique and the gravimetric (GRAV) fraction using a gravimetric technique. The TCO determination quantifies organics with boiling points from 100°C to 300°C and the gravimetric fraction includes organic compounds having boiling points over 300°C. There has been some concern that the two methods result in data that overlap, principally that TCO material is measured in the GRAV analysis. As a check of the data, TCO analysis was performed on the GRAV material of these screening samples. The data are presented in Table 3-3 and indicate that for the aerosol phase of the product gas the contribution of TCO material to GRAV results is less than 1% and may be neglected.

TABLE 3-3. RESULTS OF TCO ANALYSES PERFORMED ON GRAV MATERIAL

Sample	TCO	GRAV	TCO on GRAV
Product Gas Aerosols			
Probe	13.5 mg	692 mg	1.04 mg
ESP	82.7 mg	16,900 mg	58.3 mg
Filter	12.5 mg	376 mg	Less Than Blank

3.2.3 Gas Chromatographic Analysis - Hall Detector

A gas chromatograph (GC) equipped with a Hall 700A electrolytic conductivity detector (HECD) was used as a screening tool in addition to total chromatographable organics (TCO) analysis by GC using a flame ionization detector. The HECD may be operated in three modes—halogen, nitrogen, and sulfur specific. Using the HECD in each of the three modes for the analysis of organic extracts provided data analogous to TCO data for halogen-, nitrogen-, and sulfur-containing organic compounds. Since many organic compounds of health or ecological significance contain these heteroatoms, this technique was employed as a rapid and cost-effective screening analysis for these significant compound classes.

3.2.4 Gas Chromatography - Mass Spectrometry (GC-MS)

Data from the screening analyses were used to identify samples for detailed analysis by GC-MS. GC-MS analyses were carried out on organic extracts from the product gas, gasifier ash, cyclone dust, ash pan water and service water to provide qualitative and quantitative data for specific organic compounds. The analyses used a computer assisted GC-MS system for the EPA Priority Pollutants. Priority pollutant analyses were performed to satisfy EPA Effluent Guideline Division data needs and as a rapid and cost-effective means to identify and quantify specific compounds of potential concern, such as a number of the polynuclear aromatics.

In addition to priority pollutant analysis, the major non-priority pollutant peaks in each sample were quantified assuming a response factor of 1.0 relative to d_{10}-anthracene. This provided a more complete characterization of the organic compounds in the samples since many compounds of potential health and ecological concern are not priority pollutants.

Finally, the total unidentified chromatographable mass in each extract was quantified by relating the concentration of identified compounds to the total organic loading. These data may be used to indicate the need for further detailed sample characterization.

3.2.5 Leaching Studies

Both the gasifier ash and the cyclone dust were leached using Resource Conservation and Recovery Act (RCRA) protocol. Inorganic and organic analyses were performed on the leachates to satisfy RCRA data requirements for solid wastes.

In addition to RCRA protocol, the gasifier ash and cyclone dust were subjected to neutral leaching, which is performed using deionized water with no pH control. These leachates were prepared primarily for bioassay studies because the RCRA leachates, which are acidic, interfere with bioassay testing. In addition to the bioassay testing, elemental analysis was performed on the neutral leachates for purposes of comparison to the RCRA leachates.

3.3 Quality Assurance

To provide quality assurance for the on-site analyses, certified gas standards and standard solutions were analyzed during the sampling effort with associated samples to provide calibration data.

The samples which were not analyzed on-site were preserved according to the procedures presented in Table 3-1. Liquid samples that had short lifetimes were returned for laboratory analysis within the preservation time limits. All samples were logged on-site, and the log data entries were cross-verified upon receipt in the laboratory. The on-site log is presented in Appendix B of this document.

Solvent blanks, impinger solution blanks, and blank XAD-2 resin were analyzed in the laboratory and included in the appropriate subcontracted analyses. Liquid chromatography (LC) columns were run using solvent blanks from designated solvent lots. The same solvent lots were used throughout the organic analysis, and blanks were analyzed by infrared spectroscopy (IR), TCO, and GRAV. TCO blanks were analyzed within each set of TCO determinations.

Collection efficiencies were calculated for the impinger systems for the collection of ammonia and hydrogen cyanide. Table 3-4 presents these collection efficiencies, which were determined by dividing the amount of NH_3 or HCN collected in the second impingers (including "less than" values) by the total amount of NH_3 or HCN collected and then multiplying by 100. NH_3 concentrations in the second impinger were below the analytical detection limit, indicating no ammonia breakthrough. Minor amounts of HCN were measured in the second impinger, indicating a very low amount of carry-over.

All samples characterized for minor and trace elements were analyzed by SSMS. In addition to SSMS, the aqueous samples were analyzed for 15 elements by ICPES and 5 elements by AAS. The data are presented in Tables 3-5 and 3-6 and allow a comparison of the respective analytical techniques.

Solid samples were analyzed for 17 elements by ICPES and three elements by AAS in addition to SSMS analysis. The ICPES analyses were performed on samples resulting from two solid dissolution techniques of the solids: $HClO_4$ digestion and $LiBO_4$ fusion. Generally, the $LiBO_4$ fusion technique is more acceptable as the dissolution technique for the major and minor elements, including Al, Ba, Ca, Fe, Mg, Mn, K, Na, and Ti. The reason is that these elements are often bound as silicates, and the $LiBO_4$ fusion is more efficient in breaking down silicates than the $HClO_4$ digestion. However, the $LiBO_4$ fusion technique is performed at a high temperature (1050°C). The $HClO_4$ digestion is generally considered to be more appropriate for trace elements, including B, Cr, Co, Cu, Mo, Ni, V, and Zn, because of the relatively low temperature (200°C) used in the technique which helps prevent loss of volatile elements, and the dilution factor of the $HClO_4$ digestion is 5 to 10 times less than for $LiBO_4$ fusion. The more diluted $LiBO_4$ fusion does not adversely affect major to minor components; however, trace elements may be diluted near or below instrument detection limits. Table 3-7 presents the SSMS/ICPES analyses on two dissolutions of the solid samples.

As a quality assurance method and to provide the opportunity to evaluate ICPES analyses, NBS standard materials of coal and fly ash were digested using both $HClO_4$ digestion and $LiBO_4$ fusion, and analyzed by ICPES.

TABLE 3-4. TRACE NITROGEN GAS SPECIES CONCENTRATIONS IN THE PRODUCT GAS AND IMPINGER TRAIN COLLECTION EFFICIENCY

Sample	Impinger	µg/Impinger	Total µg	µg/Nm^3	Collection Efficiency
NH_3 #1	1	200,000±11,000	200,000	7.8E5	>97.1%
	2	<6,000			
NH_3 #2	1	205,000±1,300	205,000	7.9E5	>97.2%
	2	<6,000			
					AVG. > 97.2%
HCN #1	1[1]	34,100±730	50,700	1.6E5	>97.9%
	2[1]	710			
	1[2]	15,900			
	2[2]	<370			
HCN #2	1[1]	29,100±310	34,800	1.1E5	>98.1%
	2[1]	280			
	1[2]	5,400			
	2[2]	<390			
HCN #5	1[1]	35,800±830	47,500	2.6E5	96.8%
	2[1]	960			
	1[2]	10,200			
	2[2]	540			
					AVG. > 97.6%

[1] Analyzed as HCN

[2] Analyzed as SCN^- and converted to HCN

TABLE 3-5. ELEMENTAL CONCENTRATIONS DETERMINED BY SSMS AND ICPES/AAS FOR AQUEOUS SAMPLES

Element	Analytical Method	Ash Pan Water (RM-18)	Ash Pan Water (RM-23)	Ash Pan Water (RM-49)	Service Water (RM-5)	Ash Pan Carryover Water
Aluminum	SSMS	700	100	>900	600	>5000
	ICPES	3900	1000	2200	91	560
Antimony	SSMS	<1	<1	20	<10	20
	AAS	<3	<3	<3	<3	<3
Arsenic	SSMS	10	3	40	<10	200
	AAS	23	11	30	1	9
Barium	SSMS	1000	30	800	100	4000
	ICPES	230	91	180	39	210
Boron	SSMS	30	7	400	<10	200
	ICPES	3200	1400	3100	≤8	480
Calcium	SSMS	>10000	>10000	>10000	>20000	>10000
	ICPES	130000	45000	100000	5400	38000
Chromium	SSMS	7	<1	<1	≤30	100
	ICPES	<1	<1	<1	<1	<1
Cobalt	SSMS	<1	<1	≤1	≤20	80
	ICPES	<6	<6	<6	<6	<6
Copper	SSMS	40	10	30	70	600
	ICPES	10	3	5	33	<1
Iron	SSMS	6000	200	1000	3000	>10000
	ICPES	3400	540	1900	200	900
Magnesium	SSMS	>10000	300	2000	600	>10000
	AAS	1900	990	1300	980	6100

(Continued)

TABLE 3-5. Continued

Element	Analytical Method	Ash Pan Water (RM-18)	Ash Pan Water (RM-23)	Ash Pan Water (RM-49)	Service Water (RM-5)	Ash Pan Carryover Water
Manganese	SSMS	300	10	50	40	2000
	ICPES	96	27	50	21	10
Molybdenum	SSMS	70	40	100	300	400
	ICPES	230	110	240	3	22
Nickel	SSMS	6	<1	4	80	200
	ICPES	7	<5	4	1	1
Potassium	SSMS	>10000	>10000	>10000	19000	>10000
	ICPES	74000	30000	76000	1400	7600
Selenium	SSMS	9	2	20	<10	≤60
	AAS	10	<5	6	<5	<5
Sodium	SSMS	>10000	>4000	>5000	11000	>10000
	AAS	760000	360000	590000	6300	86000
Titanium	SSMS	700	100	100	700	>10000
	ICPES	43	<5	9	<5	<5
Vanadium	SSMS	50	1	20	20	300
	ICPES	3	<3	<3	<3	<3
Zinc	SSMS	40	20	30	80	1000
	ICPES	12	<3	1	<3	<3

All values reported in µg/l
SSMS: Spark Source Mass Spectrometry
ICPES: Inductively Coupled Argon Plasma Emission Spectrometry
AAS: Atomic Absorption Spectrophotometry
<B: Less than or equal to blank concentration
RM-X: Sample log number x

TABLE 3-6. ELEMENTAL CONCENTRATIONS DETERMINED BY SSMS & ICPES/AAS FOR PRODUCT GAS IMPINGER SAMPLES

Element	Analytical Method	Acid Impingers	Base Impingers	1st Persulfate Impinger	2nd Persulfate Impinger
Aluminum	SSMS	≤B	≤B	>2200	≤B
	ICPES	≤B	≤B	2200	520
Antimony	SSMS	≤7	<20	≤B	≤B
	AAS	<3	≤B	<3	<3
Arsenic	SSMS	7	20	≤B	≤24
	AAS	33	26	68	21
Barium	SSMS	90	≤B	≤B	≤B
	ICPES	≤B	≤B	36	≤B
Boron	SSMS	≤1	≤B	6	<1
	ICPES	49	160	6	≤B
Calcium	SSMS	2500	≤B	≤B	NC
	ICPES	89	55	9900	2900
Chromium	SSMS	1	≤B	300	≤6
	ICPES	4	13	170	<1
Cobalt	SSMS	<7	≤B	≤B	≤2
	ICPES	<6	17	<6	<6
Copper	SSMS	24	970	≤B	40
	ICPES	<1	10	<1	<1
Iron	SSMS	980	≤B	>18000	≤B
	ICPES	59	25	250000	160
Magnesium	SSMS	200	≤B	≤B	≤B
	AAS	≤B	≤B	23	27

(Continued)

TABLE 3-6. Continued

Element	Analytical Method	Acid Impingers	Base Impingers	1st Persulfate Impinger	2nd Persulfate Impinger
Manganese	SSMS	3	≤B	350	30
	ICPES	2	2	7	1
Molybdenum	SSMS	10	≤B	≤B	≤B
	ICPES	10	3	4	<2
Nickel	SSMS	36	570	≤B	≤B
	ICPES	4	12	27	≤B
Potassium	SSMS	200	≤B	>4000	>4000
	ICPES	<42	≤B	≤B	13
Selenium	SSMS	≤7	≤B	≤B	40
	AAS	2	≤B	5	43
Sodium	SSMS	≤B	C	>5000	3000
	AAS	280	C	1100	700
Titanium	SSMS	80	≤B	14500	≤B
	ICPES	<5	15	<5	<5
Vanadium	SSMS	2	≤20	7	200
	ICPES	<3	7	<3	<3
Zinc	SSMS	40	≤B	≤B	100
	ICPES	39	28	9	17

All values reported in µg/1.

SSMS: Spark Source Mass Spectrometry

ICPES: Inductively Coupled Argon Plasma Emission Spectrometry

AAS: Atomic Adsorption Spectrophotometry

≤B: Less than or equal to blank value.

C: Cation in base solution.

MC: Major component (>2000 µg/1); may not differ from blank value.

TABLE 3-7. ELEMENTAL CONCENTRATIONS DETERMINED BY SSMS AND ICPES/AAS FOR SOLID SAMPLES

Element	Analytical Method	Gasifier Ash (RM-126)	Gasifier Ash (RM-147)	Lignite (RM-73)	Lignite (Rm-77)	Cyclone Dust (RM-153 + RM-154)
Aluminum	SSMS	>1000	>1000	>1000	>1000	>1000
	ICPES/$HClO_4$	50000	37000	6200	6000	26000
	ICPES/$LiBO_4$	45000	34000	5600	5900	23000
Antimony	SSMS	1	6	<0.1	<0.2	2
	AAS	0.6	1.1	<0.5	<0.5	0.6
Arsenic	SSMS	38	68	25	4	19
	AAS	56	61	21	25	63
Barium	SSMS	>1000	>1000	>1000	900	>1000
	ICPES/$HClO_4$	3000	3200	38	28	1800
	ICPES/$LiBO_4$	3400	3200	460	400	1700
Boron	SSMS	76	760	35	45	190
	ICPES/$HClO_4$	110	88	32	37	69
	ICPES/$LiBO_4$	ND	ND	ND	ND	ND
Calcium	SSMS	>1000	>1000	>1000	>1000	>1000
	ICPES/$HClO_4$	210000	210000	15000	14000	59000
	ICPES/$LiBO_4$	96000	96000	12000	12000	35000
Chromium	SSMS	21	17	7	2	26
	ICPES/$HClO_4$	<0.2	<0.2	<0.1	2.1	34
	ICPES/$LiBO_4$	28	20	1.6	49	43
Cobalt	SSMS	1	6	≤0.2	≤0.3	2
	ICPES/$HClO_4$	17	14	2.3	2.6	8.8
	ICPES/$LiBO_4$	22	12	34	4.2	19
Copper	SSMS	2	44	9	6	12
	ICPES/$HClO_4$	44	42	70	8.0	29
	ICPES/$LiBO_4$	2.3	8.5	2.9	4.8	1.0
Iron	SSMS	>1000	>1000	>1000	>1000	>1000
	ICPES/$HClO_4$	100000	78000	24000	18000	22000
	ICPES/$LiBO_4$	56000	45000	20000	15000	14000
Magnesium	SSMS	>1000	>1000	>1000	>1000	>1000
	ICPES/$HClO_4$	58000	45000	3800	3800	16000
	ICPES/$LiBO_4$	22000	21000	3000	3000	9600

(Continued)

TABLE 3-7. Continued

Element	Analytical Method	Gasifier Ash (RM-126)	Gasifier Ash (RM-147)	Lignite (RM-73)	Lignite (Rm-77)	Cyclone Dust (RM-153 + RM-154)
Manganese	SSMS	230	>1000	19	77	310
	ICPES/HClO$_4$	240	200	13	14	64
	ICPES/LiBO$_4$	260	220	12	14	70
Molybdenum	SSMS	5	16	7	9	4
	ICPES/HClO$_4$	23	20	4.6	5.7	14
	ICPES/LiBO$_4$	≤B	≤B	≤B	1.0	≤B
Nickel	SSMS	7	13	2	0.8	4
	ICPES/HClO$_4$	26	20	3.8	6.4	20
	ICPES/LiBO$_4$	25	≤B	4.5	6.0	≤B
Potassium	SSMS	>1000	>1000	>1000	>1000	>1000
	ICPES/HClO$_4$	9600	5600	1000	1400	5700
	ICPES/LiBO$_4$	7000	4200	800	1100	4400
Selenium	SSMS	5	9	≤0.4	0.9	3
	AAS	<1	<1	<0.5	<0.5	1.2
Sodium	SSMS	>1000	>1000	>1000	>1000	>1000
	ICPES/HClO$_4$	25000	24000	3800	3600	16000
	ICPES/LiBO$_4$	24000	22000	3500	3500	12000
Titanium	SSMS	>1000	>1000	780	220	>1000
	ICPES/HClO$_4$	2200	1740	360	280	1200
	ICPES/LiBO$_4$	2100	1800	320	260	1200
Vanadium	SSMS	61	110	28	14	30
	ICPES/HClO$_4$	90	71	10	15	56
	ICPES/LiBO$_4$	63	40	13	18	48
Zinc	SSMS	12	9	2	1	60
	ICPES/HClO$_4$	38	28	8.4	8.6	71
	ICPES/LiBO$_4$	2.5	0.8	5.5	4.7	≤B

All values in µg/g. ICPES and AAS except As, Mg and Na values are average values for 2 determinations.
SSMS: Spark Source Mass Spectrometry
ICPES: Inductively Coupled Argon Emission Spectrometry
AAS: Atomic Absorption Spectrophotometry
HClO$_4$: HClO$_4$ digestion
LiBO$_4$: LiBO$_4$ fusion
ND: Not Determined: Element used in sample preparation
≤B: Less than or equal to blank concentration
RM-X: Sample log number x

The results appear in Table 3-8 and generally allow a positive appraisal of ICPES analytical techniques.

A quality assurance program was also conducted for proximate and ultimate analyses of solid samples. Three samples (lignite, gasifier ash, and cyclone dust) were prepared and split into three fractions for analysis by ANSC and Riley Stoker laboratories and Commercial Testing and Engineering (CT+E) Company (a Radian sub-contractor). In addition, the lignite sample was analyzed twice by CT+E for proximate and ultimate parameters. The results of the analyses on the three samples are presented in Table 3-9. Generally, the results compare favorably and support the reliability of the data.

TABLE 3-8. ELEMENTAL CONCENTRATIONS IN STANDARD REFERENCE MATERIALS DETERMINED BY ICPES AND BY NBS ANALYSES

Element	Analytical Method	Coal (1632a)	Fly Ash (1633)
Chromium	NBS	34.4 ± 1.5	131 ± 2
	ICPES/HC10$_4$	30.5	87.7
	ICPES/LiBO$_4$	27.7	13.9
Copper	NBS	16.5 ± 1	128 ± 5
	ICPES/HC10$_4$	15.5	126
	ICPES/LiBO$_4$	7.35	124
Iron	NBS	11100 ± 200	NA
	ICPES/HC10$_4$	13100	ND
	ICPES/LiBO$_4$	9150	ND
Manganese	NBS	28 ± 2	493 ± 7
	ICPES/HC10$_4$	25.0	415
	ICPES/LiBO$_4$	25.5	454
Nickel	NBS	28 ± 2	98 ± 3
	ICPES/HC10$_4$	22.8	94.0
	ICPES/LiBO$_4$	40.0	87.0
Vanadium	NBS	44 ± 3	214 ± 8
	ICPES/HC10$_4$	43.2	228
	ICPES/LiBO$_4$	37.1	220
Zinc	NBS	28 ± 2	210 ± 20
	ICPES/HC10$_4$	33.3	228
	ICPES/LiBO$_4$	23.6	166

Values in μg/g.

ICPES:	Inductively Coupled Argon Plasma Emission Spectrometry
NBS:	National Bureau of Standards Reference value
HC10$_4$:	HC10$_4$ digestion
LiBO$_4$:	LiBO$_4$ fusion
NA:	Not available
ND:	Not determined

TABLE 3-9. QUALITY ASSURANCE PROGRAM FOR PROXIMATE/ULTIMATE ANALYSIS

PARAMETER	LIGNITE (RM-77)					GASIFIER ASH				CYCLONE DUST			
	CT+E 01/17/80	CT+E 02/18/80	Riley Stoker	AMBC	Mean ± σ	CT+E 02/18/80	Riley Stoker	AMBC	Mean ± σ	CT+E 02/18/80	Riley Stoker	AMBC	Mean ± σ
PROXIMATE													
Ash (%)	11.44	9.23	9.8	9.96	10.11±0.94	73.78	73.0	76.57	74.45±1.88	36.86	40.8	40.09	39.25±2.10
Volatile (%)	41.47	43.82	42.0	39.90	41.80±1.62	9.93		5.28	7.60±3.29	14.75		12.52	13.64±1.12
Fixed Carbon (%)	47.09	46.95	48.2	50.14	48.10±1.47	16.29		18.15	17.22±1.32	48.39		47.39	47.89±0.71
Btu	10572	10799	10760	10846	10744±120	3537	3485	ND	3511±37	8974	8380	8408	8587±335
Sulfur (%)	0.48	0.50	0.5	0.55	0.51±0.03	1.43	1.1	0.46	1.00±0.49	1.66	1.7	1.72	1.69±0.03
Loss on Ignition (%)							27.0				59.2		
ULTIMATE													
Carbon (%)	63.47	67.38	64.6	65.35	65.20±1.65	23.92	24.4	24.30	24.21±0.25	57.29	53.1	54.63	55.01±2.12
Hydrogen (%)	4.30	3.73	4.5	4.55	4.27±0.38	0.36	0.4	0.44	0.40±0.04	1.43	1.5	1.86	1.60±0.23
Nitrogen (%)	1.06	0.88	0.96	0.51	0.85±0.24	0.27	0.22	0.14	0.21±0.07	1.55	0.62	0.72	0.96±0.51
Chlorine (%)	0.00	0.04			0.02±0.02	0.06				0.04			
Sulfur (%)	0.48	0.50	0.5	0.55	0.51±0.03	1.43	1.1	0.46	1.00±0.49	1.66	1.7	1.72	1.69±0.03
Ash (%)	11.44	9.23	9.8	9.96	10.11±0.94	73.78	73.0	76.57	74.45±1.88	36.86	40.8	40.09	39.25±2.10
Oxygen (diff.) (%)	19.25	18.24	19.64	19.08	19.05±0.59	0.18	0.88		0.53±0.49	1.17	2.28	0.98	1.48±0.70

ND - Not Determined

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SECTION 4

RESULTS

The results of the STE of the Riley Gas Producer are summarized in this section. Section 4.1 summarizes the results of the product gas characterization. Section 4.2 provides the results for the solid streams, including bioassay results, proximate/ultimate and physical analyses, and radioactivity results. Section 4.3 contains the trace element results, while Section 4.4 presents the extractable organics results. The appendices provide detailed tabulations of all data collected.

4.1 Product Gas Results

Two possible methods for the removal of particulates and condensible tars and oils from product gas are an ESP and a cool quench. In this STE, the ESP used in sampling approximated a cleanup ESP operated on gas cooled to 115°C. The condenser in the sampling train approximated a cool quench of the gas. Thus, the product gas was characterized in two fractions. This dual characterization allowed:

- an estimate of the efficiency achievable by gas cleanup systems,
- an evaluation of by-products available in the product gas, and
- a prediction of the chemical character of product gas fugitive emissions.

4.1.1 Efficiency of Gas Cleanup System

The ESP was used to remove aerosol particulate matter and liquid mist, tars and oils, from the product gas. Organic material condensing at 115°C was collected in the associated hardware (i.e., the nozzle, probe, and filter). This phase of the product gas is termed the Product Gas Aerosols.

The ESP removed 3.26×10^6 µg/Nm³ of extractable organics and 4.76×10^6 µg/Nm³ of particulates out of a total of 9.57×10^6 µg/Nm³, for a fraction removed of 39%. It should be noted that the removal of organics would most likely be increased by operation at a lower temperature. The fraction of the total collected in the probe and ESP for trace elements is shown in Table 4-1.

TABLE 4-1. COLLECTION EFFICIENCY OF PROBE AND ESP FOR TRACE ELEMENTS

Element*	Collected in Probe Plus ESP	Collected in Filters Plus Acid/Base Impingers	Total Collected	Fraction Collected in ESP + Probe (Precent)**
Aluminum	>2.6E2	>2.0E0	>2.6E2	~100
Antimony	2.1E1	<1.2E-1	2.1E1	~100
Arsenic	>3.8E2	1.3E2	>5.1E2	>74
Barium	>2.7E2	>1.0E0	>2.7E2	~100
Boron	8.1E1	5.3E2	6.1E2	13
Bromine	9.1E0	8.8E-2	9.2E0	99
Calcium	>7.1E2	>5.2E2	>1.2E3	<59
Cerium	1.6E1	<6.9E1	<8.5E1	>19
Cesium	<9.0E0	<6.9E1	<7.8E1	>12
Chlorine	1.4E2	>2.3E5	>2.3E5	<0.1
Chromium	1.7E2	1.5E1	1.8E2	94
Cobalt	<6.9E0	2.3E1	<3.0E1	<23
Copper	5.4E1	2.4E1	7.8E1	69
Fluorine	~2.6E2	~8.8E1	~3.5E2	~74
Gallium	2.6E1	8.3E1	1.1E2	24
Germanium	2.4E1	<6.9E1	<9.3E1	>26
Iodine	<3.7E0	1.6E2	1.6E2	2
Lanthanum	2.2E1	<6.9E1	<9.1E1	>24
Lead	1.8E2	≤9.1E-1	1.8E2	~100
Lithium	4.8E0	3.2E1	3.7E1	13
Magnesium	>2.8E2	~9.0E1	>3.7E2	>76
Manganese	4.1E1	2.9E2	3.3E2	12
Molybdenum	3.6E1	3.0E1	6.6E1	54
Nickel	2.9E1	4.3E1	7.2E1	40
Niobium	<5.7E0	2.3E1	<2.9E1	>20
Potassium	>6.6E2	>1.2E1	>6.7E2	>98
Rubidium	1.8E1	<2.3E1	<4.1E1	>44
Selenium	7.8E1 - 3.4E0	~5.8E0	<9.2E0	13-37
Silicon	>2.5E3	4.2E1	>2.5E3	>98
Silver	<2.2E1	<6.9E1	<9.1E1	>24
Sodium	>1.6E3	~8.1E2	>2.4E3	>67
Strontium	>2.3E2	>1.1E0	>2.3E2	~100
Sulfur	>6.3E2	1.5E5	>1.5E5	<0.4
Tellurium	<1.0E0	1.4E2	1.4E2	<0.7
Tin	≤1.6E1	<6.9E1	≤8.5E1	>17
Titanium	>2.4E2	~2.6E1	>2.6E2	>92
Vanadium	~1.6E1	2.3E1	~3.9E1	~40
Yttrium	>7.7E0	<6.9E1	<7.7E1	>9
Zinc	>3.5E2	1.9E2	>5.4E2	>65
Zirconium	1.6E1	4.9E1	6.5E1	25

*All concentrations in $\mu g/Nm^3$.

**Fraction collected = concentration collected in probe + ESP/total collected x 100.

These provide an approximation of the collection of an ESP operated at 115°C for product gas cleanup. Collection was not calculated for those elements whose concentrations were below detection limits or above the range of the analytical technique. Collection of greater than 90% was achieved for aluminum, antimony, barium, bromine, chromium, lead, potassium, silicon, strontium, and titanium.

The composition of by-products from an ESP is approximated by the composition of the aerosol particulate matter and liquid mist, tars and oils, which consists of 87 percent tars and oils and 13 percent particulates.

Downstream of the ESP, the sample gas was passed through (1) a water-cooled condenser at approximately 15°C and then through XAD-2 organic adsorbent resin for characterization of organic material, or (2) impinger trains for the characterization of trace elements, ammonia, and hydrogen cyanide. The portion of the product gas characterized downstream of the ESP is termed the Product Gas Vapors.

The organic loading of the Product Gas Vapors was 5.83×10^6 μg/Nm^3, as determined by TCO and GRAV analyses. Of this organic loading, 71.7 percent was collected in the condenser, which may approximate a quench system.

The ESP and condenser removed a combined total of 81.8 percent of the total organic loading. They also removed 83 percent of the aerosol particulate matter and liquid mist, tars and oils.

The total organic loading of the product gas is the sum of the organic loadings of the two stream fractions or 9.09×10^6 μg/Nm^3 (4.09 grains/SCF, 60°F, 1 atm). The vapor fraction accounts for 64 percent of the total organic loading, while the aerosol fraction accounts for 36 percent.

The lignite feedstock had an average volatile material content of 42.4 percent for a resulting flow rate of 284 grams per second. The extractable organic material of the Product Gas Aerosols was equivalent to 2.8 percent of the volatile material of the lignite, and the Product Gas Vapors extractable organic material was equivalent to 5.0 percent. 99.8 percent of the total extractable organic material exiting the gasifier was in the product gas; the remaining total extractable material distributed fairly evenly among the gasifier ash, cyclone dust, and ash pan water.

4.1.2 Fugitive Emissions

Gaseous fugitive emissions of the product gas would be expected to be similar to the chemical composition of the gaseous organic phase of the product gas (Product Gas Vapors) and not contain heavy organics, tars, or oils (Product Gas Aerosols). An organic sample was collected, using an organic adsorbent resin, above the gasifier and near the coal feeder lock hopper system. The resin was extracted and analyzed for organics using the same technique as that for the TCO analysis of the Product Gas Vapors extractable organics sample.

Comparison of the chromatograms of the TCO analyses of the two samples indicates a consistent similarity between the 100°C and 300°C boiling point range organics of the two samples. The data, presented in Figure 4-1, strongly indicate that organic gas phase fugitive emissions from the gasifier are very similar in composition to the Product Gas Vapors. The y-axes, peak height, are not necessarily indicative of relative stream concentrations. The magnitude of the peak heights is affected by several factors including extraction solvent volume and volume of gas sampled.

4.1.3 Product Gas Component Concentrations

A summary of product gas component concentrations is presented in Table 4-2. The concentration of each parameter is presented with one standard deviation of results. The standard deviations are derived from analytical values over the last period and indicate process variability as well as sampling and analytical variability. The concentrations of major gases, hydrocarbons, and sulfur species are average values determined by semi-continuous monitoring by process gas chromatographs. The individual analytical values are presented in Tables D-1 through D-3 in Appendix D.

The analytical values obtained with the process gas chromatographs are plotted in Figures 4-2 through 4-6. The values for O_2, CO_2, H_2, CO, and N_2 are plotted in Figure 4-2. Carbon monoxide and hydrogen are the two major gaseous fuels produced by coal gasification through the following carbon-water reaction: $C + H_2O - CO + H_2$. During periods of non-efficient production, CO and H_2 concentrations decrease, while CO_2 concentrations increase due to combustion of carbonaceous material. Discernible in Figure 4-2 are four periods during which CO and H_2 concentrations decrease and the CO_2 concentration increases. The beginning of each of these periods coincides with ash removal from the gasifier, indicating that ash removal creates a period of less efficient production, most probably due to poor air distribution. No ash removal cycles other than the four indicated occurred during the analysis periods.

4.2 Solid Stream Results

4.2.1 Bioassay Results

Acute bioassay tests were performed on samples of the gasifier ash and cyclone dust solids and neutral leachates according to the test matrix presented in Table 4-3. The results of the health tests indicate no major or minor effects. The results of the ecological tests, however, show that both gasifier ash and cyclone dust neutral leachates are quite toxic to freshwater algae. The source of this toxicity was not identified in the chemical analyses.

Detailed results of the Ames, CHO, RAM, and RAT tests performed by the sub-contractor, A.D. Little, Inc., are presented in Appendix G. In addition, Appendix H contains detailed results of phytotoxicity tests conducted at EG and G, Bionomics Marine Research Laboratory, on the freshwater alga, Selenastrum capricornutum.

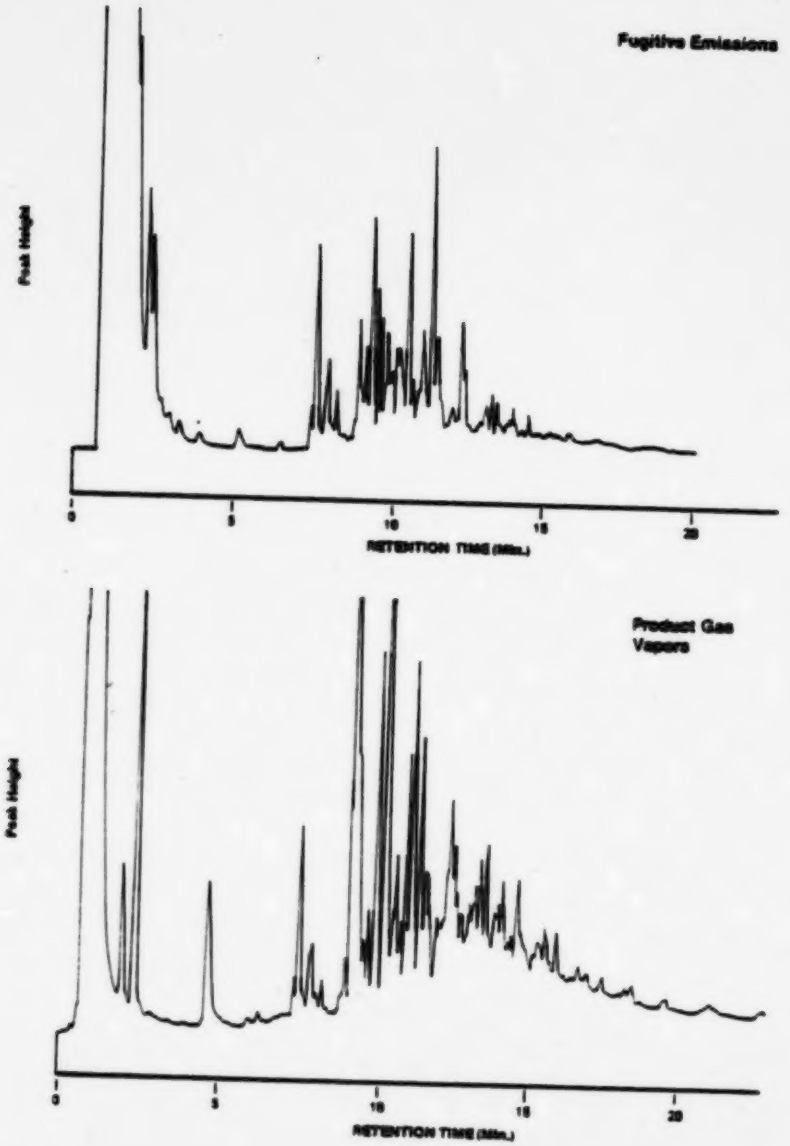

Figure 4-1. Comparison of FID/GC Chromatographs of Fugitive Emissions and Product Gas Vapors

TABLE 4-2. PRODUCT GAS COMPOSITION

Parameter	Concentration ± σ	
H_2[a]	1.3 E7 ± 1.0 E6 μg/Nm^3	16 ± 1.2%
CO[a]	3.0 E8 ± 1.8 E7 μg/Nm^3	26 ± 1.6%
CO_2[a]	1.2 E8 ± 1.9 E7 μg/Nm^3	6.8 ± 1.0%
O_2[a]	6.3 E6 ± 5.2 E5 μg/Nm^3	0.48 ± 0.04%
Ar[a]	9.8 E6 ± 8.2 E5 μg/Nm^3	0.60 ± 0.05%
N_2[a]	5.0 E8 ± 3.6 E7 μg/Nm^3	43 ± 3.2%
CH_4[a]	6.5 E6 ± 1.9 E6 μg/Nm^3	9900 ± 2900 ppm
C_2H_6[a]	6.1 E5 ± 1.6 E5 μg/Nm^3	500 ± 130 ppm
C_2H_4[a]	3.0 E5 ± 7.1 E4 μg/Nm^3	260 ± 62 ppm
C_3H_8[a]	4.0 E5 ± 7.3 E4 μg/Nm^3	220 ± 40 ppm
C_4 + (as C_4H_{10})[a]	8.5 E5 ± 2.1 E5 μg/Nm^3	360 ± 88 ppm
H_2S[a]	1.5 E6 ± 4.6 E5 μg/Nm^3	1100 ± 330 ppm
COS[a]	2.9 E5 ± 4.9 E4 μg/Nm^3	120 ± 20 ppm
Benzene[b]	2.6 E5 ± 7.8 E4 μg/Nm^3	81 ± 26 ppm
Toluene[b]	1.6 E5 ± 2.8 E4 μg/Nm^3	43 ± 6.6 ppm
Xylene[b]	1.6 E5 ± 8.5 E4 μg/Nm^3	37 ± 19 ppm
NH_3[c]	7.8 E5 ± 1.0 E4 μg/Nm^3	1100 ± 10 ppm
HCN[c]	1.8 E5 ± 7.6 E4 μg/Nm^3	160 ± 71 ppm
Moisture[d]	1.9 E8 ± 1.8 E7 μg/Nm^3	26 ± 2.5%
Extractable Organics	9.1 E6 μg/Nm^3	4.1 grains/SCF
Particulate	4.8 E5 μg/Nm^3	0.2 grains/SCF

[a] Process gas chromatographs analysis.
[b] Sample collected on charcoal tube, FID/GC analysis.
[c] Sample collected in impingers, colorimetric analysis.
[d] Sample collected in impingers, gravimetric analysis.
a E b = a x 10^b
Nm^3 = normal cubic meters (20°C, 1 atm., dry)
SCF = standard cubic foot (60°F, 1 atm., dry)

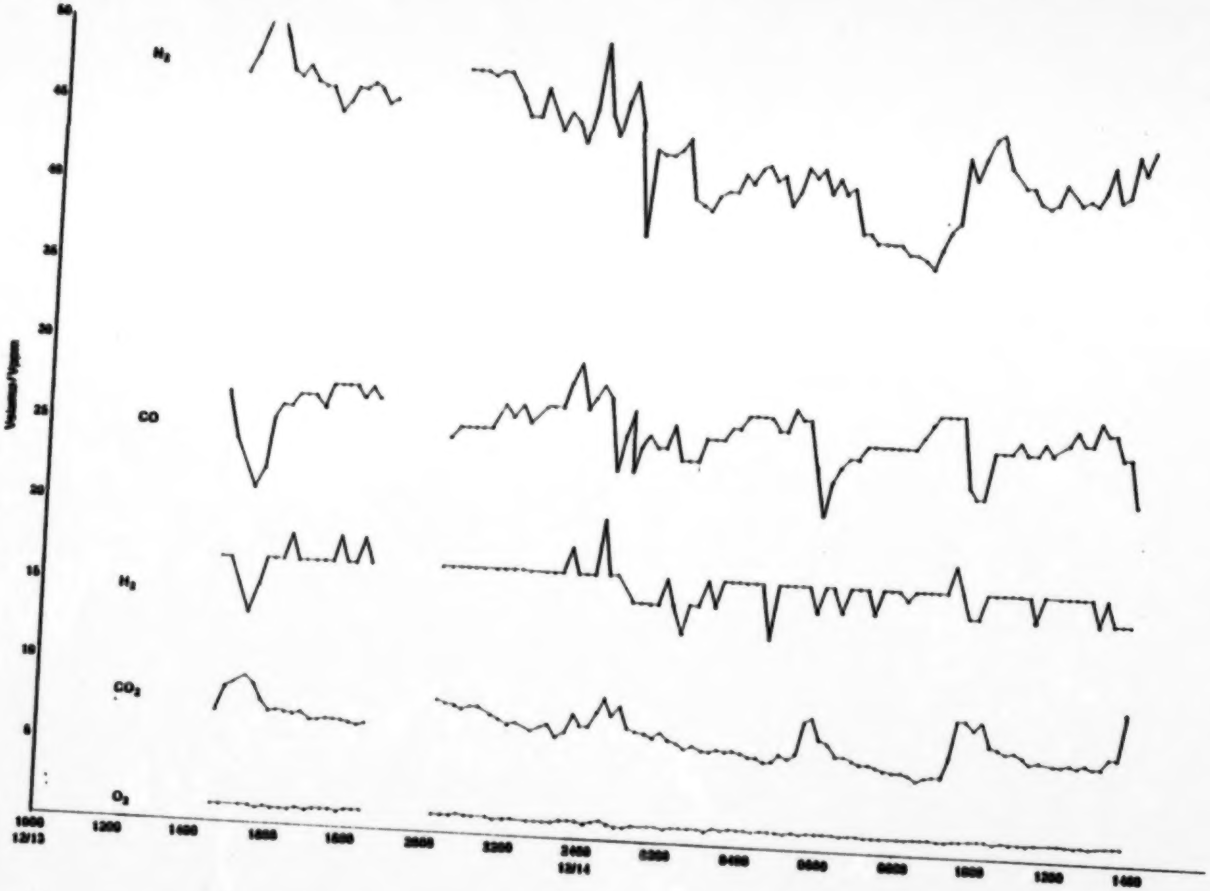

Figure 4-2. Process GC Analytical Values for Major Gases

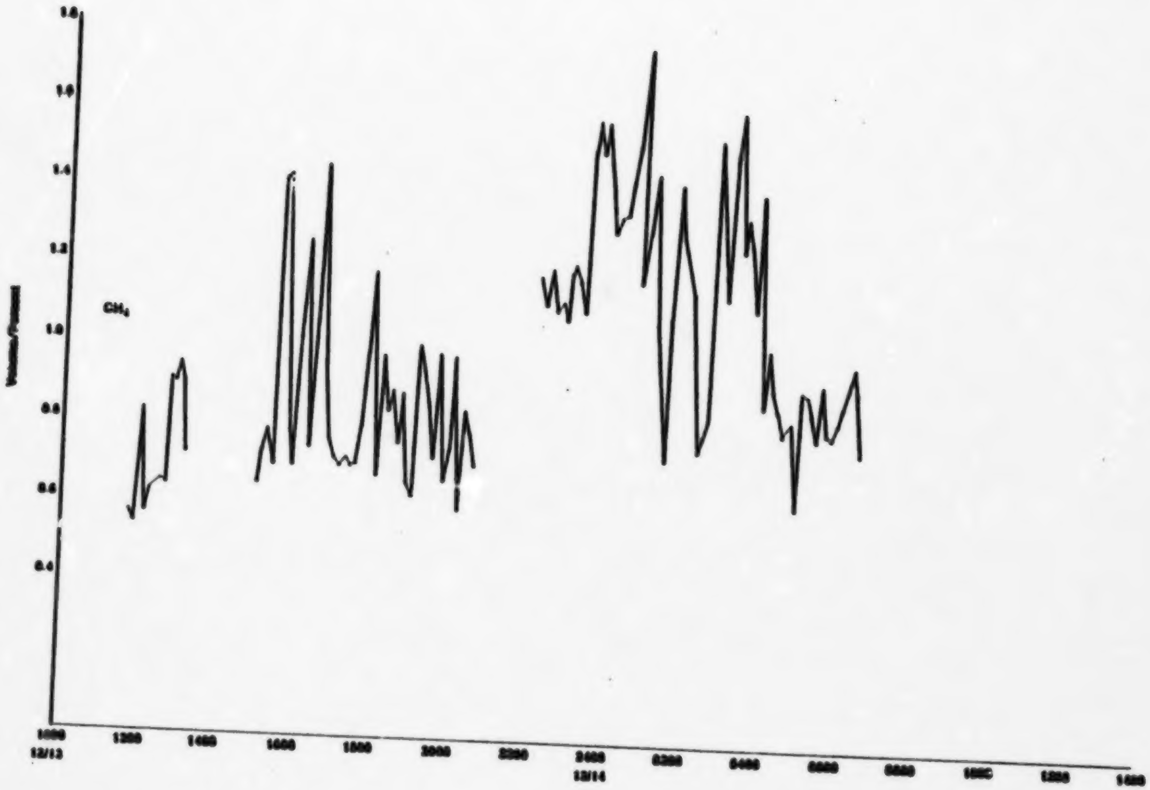

Figure 4-3. Process GC Analytical Values for Methane

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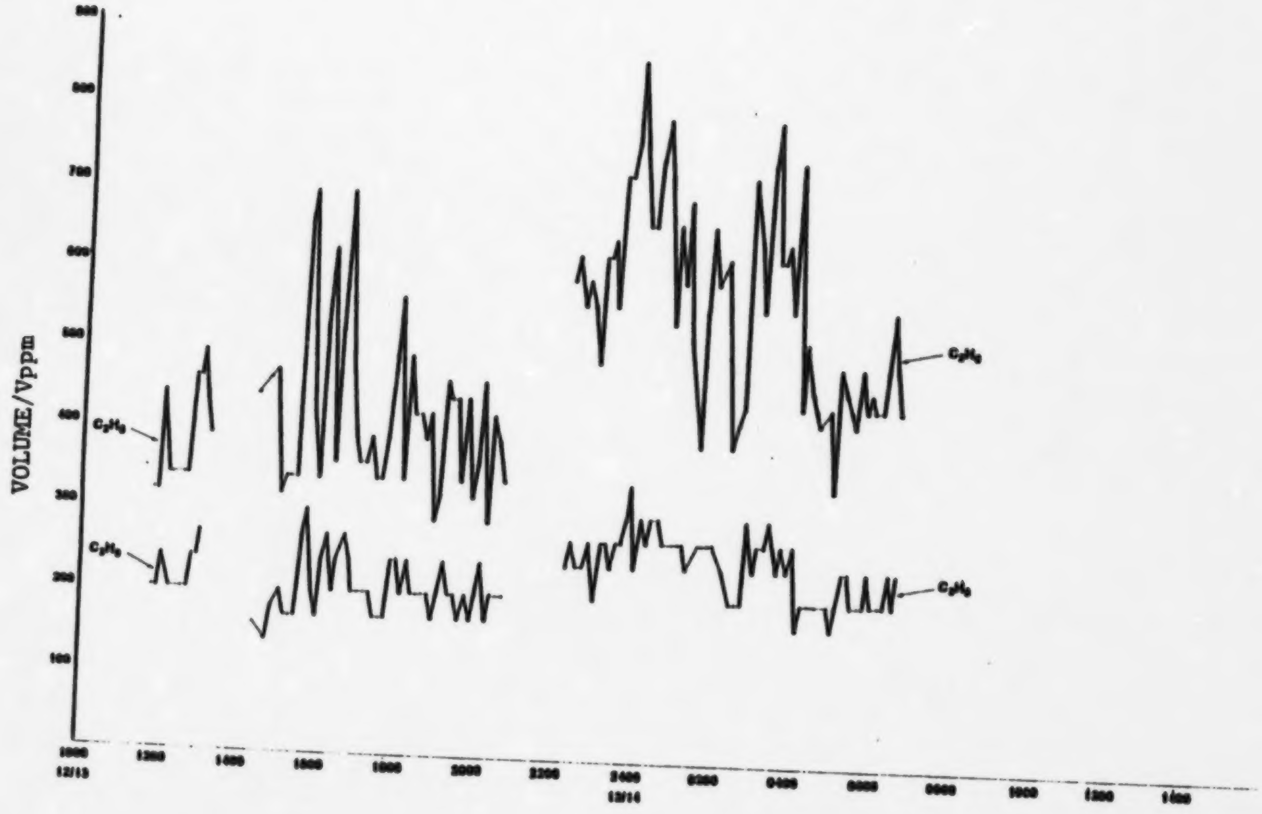

Figure 4-4. Process GC Analytical Values for Ethane and Propane

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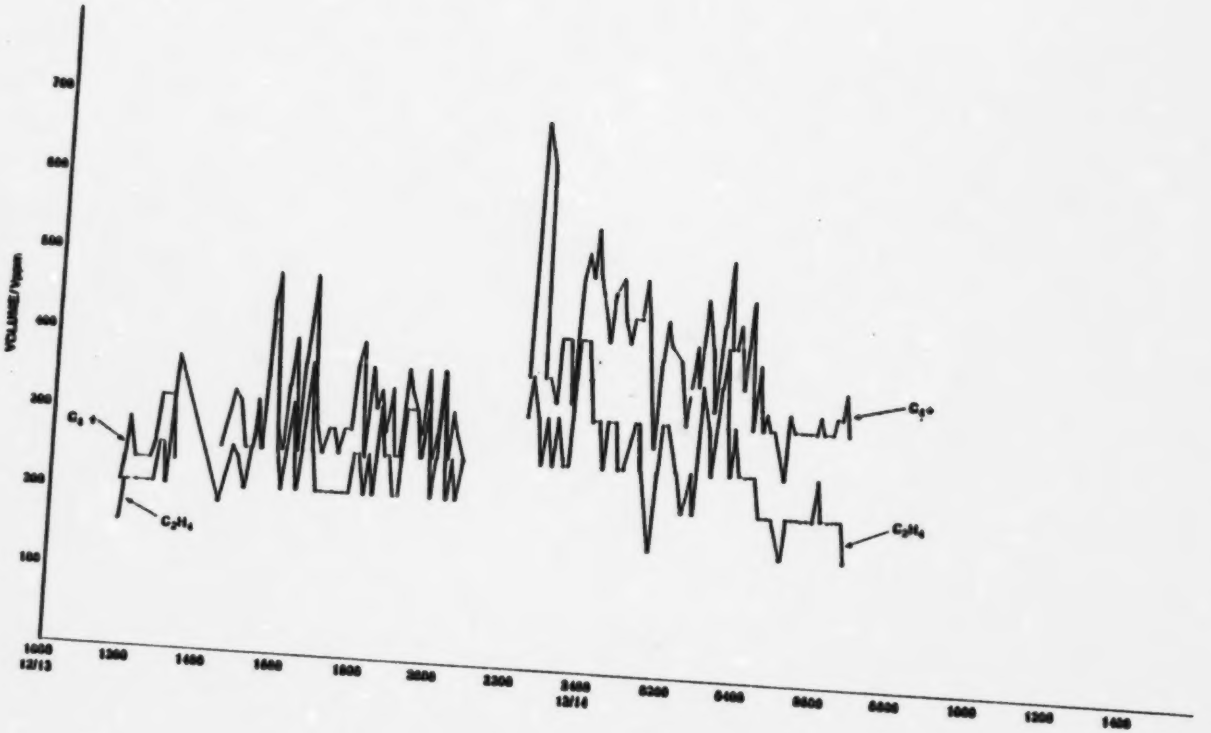

Figure 4-5. Process GC Analytical Values for C_4+ Isomers and Ethylenes

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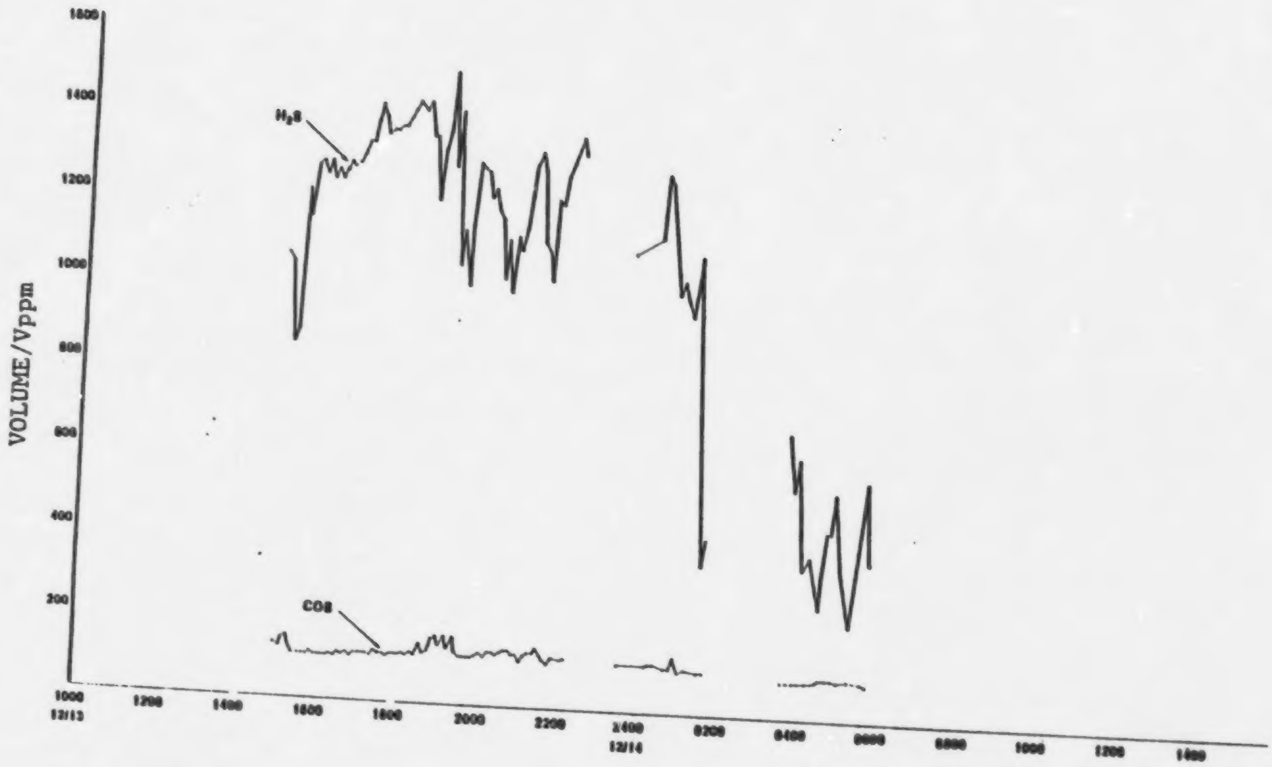

Figure 4-6. Process GC Analytical Values for Sulfur Species

TABLE 4-3. BIOASSAY TEST MATRIX

Sample	Test Ames[1] (Health)	 CHO[2] (Health)	 RAM[3] (Health)	 RAT[4] (Health)	 Freshwater Alga[5] (Ecology)
Cyclone Dust	X	X	X		
Gasifier Ash	X	X	X		
Gasifier Ash Neutral Leachate	X	X		X	X
Cyclone Dust Neutral Leachate	X	X		X	X

[1] Salmonella Mutagenesis Assay (Ames)
[2] Chinese Hamster Ovary Clonal Toxicity Assay (In Vitro Cytotoxicity Assay)
[3] Rabbit Alveolar Macrophage Assay (In Vitro Cytotoxicity Assay)
[4] Rodent Acute Toxicity (Acute in Vivo Toxicological Test)
[5] Freshwater Alga (*Selenastrum capricornutum*) Toxicity Assay

4.2.1.1 Salmonella Mutagenesis Assay (Ames) Results

The Ames assay was performed on *Salmonella typhimurium* with and without metabolic activation in a culture medium containing insufficient histidine to allow the test strains to colonize. After incubation for 48 hours, the mutant colonies formed by histidine-positive revertants were counted.

The results of the Salmonella Mutagenesis (Ames) assay are presented in Table 4-4. No sample appeared to be mutagenic in either the presence or absence of metabolic activation.

4.2.1.2 In Vitro Cytotoxicity Assay Results (RAM, CHO)

In vitro cytotoxicity was determined with the RAM and CHO assays. The RAM assay involved the preparation of rabbit alveolar macrophages by lung lavage in situ. The macrophages were incubated for 20 hours in media containing cyclone dust or gasifier ash. After incubation, the cells were trypsinized and cell viability and total protein and adenosine triphosphate (ATP) content were determined. For the CHO assay, cultured cells of Chinese hamster ovary fibroblasts were incubated in media containing sample extracts of the cyclone dust, gasifier ash, gasifier ash neutral leachate, and cyclone dust neutral leachate.

TABLE 4-4. SUMMARY OF RESULTS OF SALMONELLA MUTAGENESIS (AMES) ASSAY

Sample	Mutagenicity
Cyclone Dust	Negative
Gasifier Ash	Negative
Gasifier Ash Neutral Leachate	Negative
Cyclone Dust Neutral Leachate	Negative

Table 4-5 summarizes the results of the vitro cytotoxicity tests. The toxicity is expressed as ED$_{50}$ values. An ED$_{50}$ value is the concentration of the sample at which 50 percent of the cells would be killed.

TABLE 4-5. SUMMARY OF RESULTS OF IN VITRO CYTOTOXICITY TESTS

Sample	Test System	Toxicity (ED$_{50}$)
Cyclone Dust	RAM	No detectable toxicity (>1000 µg/ml)
	CHO	Low toxicity (970 µg/ml)
Gasifier Ash	RAM	Low toxicity (740 µg/ml)
	CHO	No detectable toxicity (>1000 µg/ml)
Gasifier Ash Neutral Leachate	CHO	Low toxicity (580 µl/ml)
Cyclone Dust Neutral Leachate	CHO	No detectable toxicity (>600 µl/ml)

In the RAM assay, the cyclone dust sample caused no detectable toxicity, and the gasifier ash sample caused low toxicity. The ED$_{50}$ values for the cyclone dust and the gasifier ash were >1000 µg/ml and 740 µg/ml, respectively. In the CHO assay, the cyclone dust caused low toxicity (ED$_{50}$ = 970 μg/ml), and its neutral leachate caused no detectable toxicity (ED$_{50}$ >600 μl/ml). The gasifier ash caused no detectable toxicity (ED$_{50}$ = >1000 μg/ml), and its neutral leachate caused low toxicity (ED$_{50}$ = 580 μl/ml).

The detection limit for the gasifier ash neutral leachate is lower than that for the cyclone dust neutral leachate. This can possibly be explained by the fact that tests of the sample of gasifier ash neutral leachate at 20 μl/ml and 6 μl/ml contained numerous small colonies that gave unusually high readings (see Appendix G).

4.2.1.3 Rodent Acute Toxicity (RAT) Test Results

A summary of the results of acute oral toxicity tests (RAT) in mice are presented in Table 4-6. A single dose of 10 ml/kg of gasifier ash neutral leachate and a single dose of 10 ml/kg of cyclone dust neutral leachate were administered by lavage to male and female mice (5 males and 5 females). These samples had no lethal effects at a dose of 10 ml/kg. On the 15th day following dosing, the animals were killed and autopsied. Several animals in each experimental group had white coronary blood vessels; some of the same animals exhibited local cardiac muscle ischemia. The significance of these observations is unknown. Mean body weights on the 15th day were 4% higher than the mean initial weight for each group.

TABLE 4-6. SUMMARY OF RESULTS OF ACUTE ORAL TOXICITY TESTS (RAT) IN MICE

Sample	Mortality (Day 15)	% Weight Gain (Day 15)	White Coronary Blood Vessels	Local Cardiac Ischemia*
Gasifier Ash Neutral Leachate	0/10	4%	3/10	1/10
Cyclone Dust Neutral Leachate	0/10	4%	4/10	1/10
Tap Water Control	0/10	4%	0/10	1/10

*Observed at autopsy.

4.2.1.4 Freshwater Alga

Table 4-7 presents a summary of the results of phytotoxicity tests to determine the effect of cyclone dust and gasifier ash neutral leachates on the freshwater alga Selenastrum capricornutum. The results of the phytotoxicity tests are reported as 14-day EC$_{50}$'s. A 14-day EC$_{50}$ is the concentration of each neutral leachate that is estimated to cause a 50% decrease of biomass (measured as dry cell weight) in an exposed culture as compared to a control after 14 days of exposure.

TABLE 4-7. SUMMARY OF RESULTS OF FRESHWATER ALGA TOXICITY TESTS

Sample	Leachate Concentration+ (%)	Dry Cell Weight Day 14 (% Change)	EC$_{50}$* Day 14 (Leachate Concentration+)
Cyclone Dust Neutral Leachate	0.1	0	3%
	0.3	+14	
	0.6	-4	
	1	-14	
	3	-54	
	6	-96	
Gasifier Ash Neutral Leachate	0.1	-9	4%
	0.3	0	
	0.6	0	
	1	-4	
	3	-14	
	6	-86	

+Concentration is the percentage of leachate in the algal growth medium based on volume:volume measurements.

*14-day EC$_{50}$ is the concentration of effluent estimated to cause a 50% decrease of biomass.

After 14 days of exposure to cyclone dust neutral leachate, the decrease in dry cell weight varied from 0% in cultures exposed to 0.1% leachate to 96% in cultures exposed to 6% leachate. The graphically interpolated 14-day EC$_{50}$ (based on decrease of dry cell weight) was 3% cyclone dust neutral leachate.

In the case of gasifier ash neutral leachate, the decrease of dry cell weight after 14 days of exposure was from 0% in cultures exposed to 0.3% and 0.6% leachate to 86% in those exposed to 6% leachate. The graphically interpolated 14-day EC$_{50}$ (based on dry cell weight) was 4% leachate.

Both the cyclone dust and gasifier ash neutral leachates were quite toxic to the alga. It should be pointed out that EG and G conducted the tests at much lower concentrations than those recommended by EPA (see Appendix H).

The lower concentrations were used because the exposure of the cultures to the recommended concentrations caused a significant effect after only 4 days.

4.2.2 Proximate/Ultimate and Physical Analyses

4.2.2.1 Proximate and Ultimate Analyses

Ultimate and proximate analyses were performed on six lignite samples, two gasifier ash samples, two cyclone dust samples and one product gas tar sample. Table 4-8 presents the average values, the range of values, and the standard deviations of the results (all based upon dry samples). Except for the cyclone dust, the samples were collected during the 24-hour balance period and illustrate the variability of process conditions. Samples of the cyclone dust were received from Riley Stoker after process operation had been completed.

Seventeen samples of the lignite feedstock during the 24-hour sampling period were analyzed for sulfur by a subcontract laboratory. The sulfur value shown in Table 4-8 is the average of these analyses. The individual sulfur determinations are presented in Table F-15 of Appendix F.

The results presented in Table 4-8 were used in preparing the component material balance presented in Table 2-1.

4.2.2.2 Particle Size Distribution

Particle size distribution was determined on six lignite, five gasifier ash, and two cyclone dust samples. Figures F-1, F-6, and F-10 in Appendix F present plots of the average particle size of the samples as a function of sample mass for the lignite, gasifier ash, and cyclone dust, respectively.

4.2.2.3 Moisture

Six lignite samples were analyzed for moisture content. The average value is 32.8 percent moisture in the lignite. Individual sample results are presented in Table F-22 in Appendix F.

4.2.3 Radioactivity Results

Gross alpha and beta radioactivity was determined on two samples of lignite, a composite cyclone dust, and a composite gasifier ash. In addition, gamma and alpha spectrometry was used for specific isotope analyses of these solid samples. Complete analytical results for gross alpha and beta and specific isotope analyses are presented in Appendix F.

The discharge limits of radioactive isotopes are presently not regulated. Regulatory discharge limits have been proposed for only one radioactive isotope, Radium-226. The Resource Conservation and Recovery Act proposed a discharge concentration limit for Radium-226 of five picocuries per gram of solid waste (Ref. 8). Neither the cyclone dust nor the gasifier ash had

TABLE 4-8. PROXIMATE AND ULTIMATE ANALYTICAL RESULTS FOR SOLID STREAMS

	Gasifier Ash[1]			Cyclone Dust[2]			Lignite[3]			
	Average	Range	Standard Deviation	Average	Range	Standard Deviation	Average	Range	Standard Deviation	Product Gas Tar[5]
Proximate Analysis (dry basis)										
% Ash	62.54	51.63-72.29	10.35	39.93	38.44-41.39	2.09	12.09	8.00-14.02	2.18	0.20
% Volatile	10.59	9.40-11.20	1.03	15.00	14.93-15.07	0.10	42.40	40.59-43.23	1.24	96.66
% Fixed Carbon	26.87	18.31-37.17	9.55	45.08	43.54-46.63	2.18	45.51	41.91-49.46	2.81	3.14
Btu/lb	4993	3853-6593	1427	8478	8297-8658	255	10630	9938-11149	262	11261
% Sulfur	1.64	1.54- 1.72	0.09	1.67	1.60- 1.74	0.10	1.10[4]	0.37- 3.10	0.86	0.33
Ultimate Analysis (dry basis)										
% Carbon	35.36	27.02-45.56	9.41	53.69	52.58-54.80	1.57	63.32	61.96-66.50	1.64	58.57
% Hydrogen	0.61	0.48- 0.79	0.16	1.52	1.49- 1.55	0.04	4.31	4.11- 4.69	0.20	8.40
% Nitrogen	0.46	0.41- 0.55	0.08	0.82	0.80- 0.83	0.02	1.02	0.91- 1.06	0.06	0.69
% Chlorine	0.003	0.00- 0.01	0.005	0			0.002	0.00- 0.01	0.004	0.06
% Sulfur	1.64	1.54- 1.72	0.09	1.67	1.60- 1.74	0.10	1.08[4]	0.48- 3.10	0.86	0.33
% Ash	62.54	51.63-72.29	10.35	39.92	38.44-41.39	2.09	12.09	8.00-14.02	2.18	0.20
% Oxygen (diff)	0			2.39	1.94- 2.84	0.64	17.94	15.77-19.25	1.28	30.75

[1] Three samples.

[2] Two samples.

[3] Six samples.

[4] Sulfur value is average of 17 lignite samples.

[5] Sample collected in on-line GC's sample gas clean-up ESP.

Radium-226 concentrations that exceeded this level. Table 4-9 presents the proposed RCRA value and the Radium-226 radioactivity concentrations of the cyclone dust, gasifier ash, and lignite.

TABLE 4-9. PROPOSED RCRA STANDARD AND COMPARISON OF RADIUM-226 OF GASIFIER ASH AND CYLONE DUST

	Radium-226 pCi/g
Proposed RCRA Value	5.0
Cyclone Dust	3.70
Gasifier Ash	2.70
Lignite RM-73	0.20
Lignite RM-77	0.30

As a comparison of specific isotope analysis (SIA) to SSMS analysis for total elemental concentration, the weight fraction of each isotope of uranium and thorium was determined using the following equation:

$$W = \frac{AM}{N_o \lambda}$$

where W = mass of nuclide per unit mass of sample
A = activity of nuclide per unit mass of sample
= Ci/g x 3.7 x 10 ml atoms/sec/Ci
M = nuclide mass (grams/mole)
N_o = Avogadro constant
λ = Decay constant
$= \frac{\ln 2}{t_{1/2}}$
$t_{1/2}$ = nuclide half life in seconds

The combination of the individual isotopes were summed and compared to SSMS analytical results. Table 4-10 presents this comparison of SIA and SSMS analyses. The total element concentrations calculated from SIA agree well with SSMS results for the cyclone dust. However, for the two coal samples and the gasifier ash, SIA results are consistently lower than SSMS. Although SSMS is only a semiquantitative technique, the consistency of this comparison for uranium and thorium indicates that the SIA results are possibly biased low.

TABLE 4-10. COMPARISON OF SPECIFIC ISOTOPE ANALYSIS AND SSMS ANALYSIS

		Lignite RM-73	Lignite RM-77	Cyclone Dust	Gasifier Ash
Uranium	SIA	0.60	0.64	2.6	4.0
	SSMS	2	3	3	15
Thorium	SIA	1.5	0.99	5.2	1.0
	SSMS	3	4	4	34

Table 4-11 compares the relative percentages of the uranium isotopes to their natural isotopic abundances. The individual isotopes are present in the samples at approximately their natural abundances. The deviations from natural abundance are well within the accuracy of the technique.

TABLE 4-11. RELATIVE ABUNDANCE OF URANIUM ISOTOPES USING SPECIFIC ISOTOPE ANALYSES

	Natural Abundance %	Lignite RM-73 %	Lignite RM-77 %	Cyclone Dust %	Gasifier Ash %
U^{234}	0.0056	0.0048	0.0055	0.0053	0.0047
U^{235}	0.72	2.16	0.96	1.63	0.72
U^{238}	99.27	97.84	99.04	98.37	99.28

The alpha-emitting and beta-emitting specific isotopes were summed to give estimates of gross alpha and beta radioactivity. These estimates are compared to the gross alpha and beta results in Table 4-12. The variances in the gross alpha and beta results preclude any definitive conclusions from this comparison for most of the results. The total alpha emissions from the cyclone dust and gasifier ash are significantly higher than the estimate from SIA; however, the error limits are quite high for these analyses and are overlapping.

TABLE 4-12. GROSS ALPHA AND BETA ANALYSIS AND SPECIFIC ISOTOPE ANALYSIS COMPARISON

	Alpha Radiation		Beta Emission	
	Gross	Specific Isotope	Gross	Specific Isotope
Lignite (RM-73)	2.2 ± 3.3	1.3 ± 0.2	2 ± 16	5.5 + 5.0
Lignite (RM-77)	0.6 ± 2.6	1.4 ± 0.2	6 ± 15	- - -
Cyclone Dust (Composite)	17 ± 7	8.7 ± 0.8	0 ± 15	10.6 + 3.3
Gasifier Ash (Composite)	25 ± 8	9.6 ± 0.9	18 ± 16	11.3 + 2.9

4.3 Trace Element Results

Inorganic elements enter the gasification system in the lignite feedstock. The eventual environmental impact of these elements is dependent on the form in which they leave the gasification system and their mobility in the environment. Elements leaving the gasifier with the ash may dissolve in the ash pan water or be leached from the ash following disposal. The quantity and solubility of elements in the gasifier ash therefore is important in the determination of water treatment requirements and limitations on ash disposal by landfill. Elements leaving the gasifier with the product gas may be collected in the cyclone and have an impact on disposal of the cyclone dust. They also may remain with the product gas, thus contributing to the emissions resulting from utilization of the product gas as a combustion fuel. During gasification, the fate of these elements is hypothesized to be one of the following:

- Elements which are nonvolatile or do not react to form volatile compounds remain in the solids and are distributed in the system with the coal ash.
- Highly volatile elements or compounds are vaporized and leave in the product gas.
- Moderately volatile elements are vaporized and condense, either partially or completely, by nucleation or deposition upon available particulates; these elements are more concentrated in the cyclone dust or in the particulates in the product gas.

This theory of elemental behavior in the gasification process has been used as a basis for identification of predictable patterns of behavior for individual elements. The validity of the theory and the elemental behavior has been evaluated by reviewing the distribution of elements in the effluent streams.

4.3.1 Mass Flow Rates

The mass flow rates of the minor and trace elements entering the process with the lignite and service water and leaving in the discharge streams were calculated by multiplying the elemental concentrations of each stream (Tables F-25 through F-28 in Appendix F) by the flow rate of the stream (Table 2-1). These elemental mass flow rates are presented in Table 4-13.

4.3.2 Elemental Distribution

The distribution of elements among the five discharge streams was calculated from the mass flow rates for these streams. Table 4-14 gives the stream elemental distributions as percentages of the total of each element leaving the system.

In this discussion, an element was considered to be highly volatile if 25 percent or more of its total mass was found in the vapor portion of the product gas. As Table 4-14 shows, the following elements were highly volatile:

bromine
cesium
chlorine
fluorine
gallium
iodine
mercury
selenium
sulfur
tellurium

A number of elements were found to have 25 percent or more of their total mass associated with the cyclone dust and aerosol portion of the product gas, thus exhibiting moderately volatile behavior:

antimony
arsenic
chromium
germanium
lead
tin
zinc

The following elements exhibit nonvolatile behavior and exit the system primarily in the gasifier ash:

TABLE 4-13. ELEMENTAL MASS FLOW RATES^{+}

	LIGNITE (Flow Rate = 670 g/sec)	SERVICE WATER (Flow Rate = 2200 g/sec)	PRODUCT GAS AEROSOLS (Flow Rate = 9.0 g/sec)	PRODUCT GAS VAPORS (Flow Rate = 2300 g/sec)		GASIFIER ASH (Flow Rate = 75 g/sec)	CYCLONE DUST (Flow Rate = 4 g/sec)	ASH PAN WATER (Flow Rate = 2200 g/sec)
				Acid/Base Impingers	Persulfate Impingers			
Aluminum	4.0*	2.0E-4*	>1.3 E-3	LB*	1.2 E-2*	3.4*	9.2 E-2*	5.3 E-3*
Antimony	<3.4 E-4**	<6.6 E-6**	9.9 E-5	LB**	<2.4 E-5**	4.3 E-5**	3.4 E-6**	<6.6 E-6**
Arsenic	1.7 E-2**	2.2 E-6	>1.6 E-3	3.1 E-4**	3.9 E-4**	4.2 E-3**	2.5 E-4**	4.6 E-5**
Barium	2.7 E-1*	8.6 E-5	>1.2 E-3	LB*	1.5 E-4*	2.6 E-1*	6.8 E-3*	3.7 E-4*
Beryllium	2.0 E-4	<2.2 E-5	<3.0 E-6	<1.7 E-4	<3.6 E-5	2.3 E-5	2.8 E-6	<2.2 E-6
Bismuth	<1.3 E-4	<2.2 E-5	<1.1 E-5	<1.7 E-4	<3.6 E-5	<1.5 E-5	8.0 E-7	<2.2 E-6
Boron	2.5 E-2*	LB*	2.4 E-4	1.3 E-3*	LB*	8.2 E-3*	2.8 E-4*	5.7 E-3*
Bromine	1.3 E-3	2.2 E-4	2.4 E-5	LB	8.9 E-4	2.2 E-4	1.2 E-5	7.0 E-5
Cadmium	2.0 E-3	<2.2 E-5	<1.1 E-5	<1.7 E-4	<3.6 E-5	<1.5 E-5	<4 E-7	<2.2 E-6
Calcium	8.0*	2.1 E-2*	>2.5 E-3	1.2 E-3*	5.6 E-2*	7.2*	1.4 E-1*	2.0 E-1*
Cerium	3.4 E-3	6.6 E-5	8.2 E-5	<1.7 E4	LB	3.5 E-3	9.6 E-5	<8.1 E-6
Cesium	2.0 E-4	<2.2 E-5	<4.3 E-5	<1.7 E-4	1.2 E-4	1.5 E-4	1.2 E-5	<8.1 E-6
Chlorine	9.4 E-3	6.6 E-4	6.5 E-4	>5.6 E-1	>8.2 E-2	3.4 E-3	2.0 E-4	1.1 E-2
Chromium	3.3 E-3*	<2.2 E-6	8.1 E-4	3.4 E-5*	9.9 E-5*	<1.5 E-5**	1.7 E-4*	<2.2 E-6*
Cobalt	1.7 E-3*	<1.3 E-5*	≤2.5 E-5*	5.6 E-5*	<5.1 E-5*	1.3 E-3*	3.5 E-5*	<1.3 E-5*
Copper	5.4 E-3*	7.3 E-5*	2.3 E-4	5.6 E-5*	<8.4 E-6*	3.3 E-3*	1.2 E-4*	1.3 E-5
Dysprosium	<1.3 E-4	<2.2 E-5	<7.4 E-6	<1.7 E-4	<3.6 E-5	1.5 E-4	1.6 E-5	<2.2 E-6
Erbium	<1.3 E-4	<2.2 E-5	<3.7 E-6	<1.7 E-4	<3.6 E-5	5.2 E-5	3.2 E-6	<2.2 E-6
Europium	2.0 E-4	<2.2 E-5	<3.9 E-6	<1.7 E-4	<3.6 E-5	7.5 E-5	4.0 E-6	<2.2 E-6
Fluorine	4.5 E-2	4.4 E-5	1.2 E-3	2.1 E-4	8.2 E-3	1.2 E-2	5.6 E-4	2.0 E-3
Gadolinium	≤2.7 E-4	<2.2 E-5	<7.4 E-6	<1.7 E-4	<3.6 E-5	1.5 E-4	8.0 E-6	<2.2 E-6
Gallium	1.3 E-3	2.2 E-5	6.5 E-5	2.0 E-4	LB	1.1 E-4	4.8 E-5	1.4 E-5
Germanium	<1.3 E-4	<2.2 E-5	1.2 E-4	<1.7 E-4	2.9 E-5	3.0 E4	8.0 E-6	<5.1 E-6
Gold	<1.3 E-4	<2.2 E-5	<2.9 E-6	<1.7 E-4	<3.6 E-5	<1.5 E-5	<4.0 E-7	<2.2 E-6
Hafnium	<1.3 E-4	<2.2 E-5	<5.0 E-6	<1.7 E-4	<3.6 E-5	≤1.5 E-4	2.0 E-6	<2.2 E-6
Holmium	<1.3 E-4	<2.2 E-5	<6.2 E-6	<1.7 E-4	<3.6 E-5	7.5 E-5	4.0 E-6	<2.2 E-6
Iodine	1.3 E-4	<2.2 E-6	<1.5 E-5	3.9 E-4	LB	3.0 E-5	3.6 E-6	1.1 E-5
Iridium	1.3 E-4	<2.2 E-5	<2.8 E-6	<1.7 E-4	<3.6 E-5	<1.5 E-5	<4.0 E-7	<2.2 E-6
Iron	1.0 E1*	4.4 E-4*	>1.2 E-3	5.1 E-4*	1.7 E-3*	4.2*	5.6 E-2*	4.2 E-3*
Lanthanum	1.3 E-3	1.1 E-4	1.1 E-4	<1.7 E-4	LB	3.5 E-3	9.6 E-5	<8.1 E-6
Lead	1.3 E-3	<2.2 E-5	9.0 E-4	LB	4.1 E-4	6.0 E-4	1.5 E-4	<2.9 E-6
Lithium	1.3 E-3	<2.2 E-5	1.7 E-5	7.7 E-5	1.2 E-4	4.5 E-4	4.0 E-5	<5.9 E-6
Lutetium	<1.3 E-4	<2.2 E-5	<3.8 E-6	<1.7 E-4	<3.6 E-5	<1.5 E-5	4.0 E-7	<2.2 E-6
Magnesium	2.0*	1.4 E-3*	>1.3 E-3	2.1 E-4*	4.6 E-4*	1.6*	3.8 E-2*	3.1 E-3*
Manganese	9.4 E-3*	4.6 E-5*	2.2 E-4	7.0 E-4*	3.4 E-5*	1.9 E-2*	2.7 E-4*	1.3 E-4*
Mercury	1.3 E-4	<1.1 E-6**	NR	3.4 E-6**	2.6 E-5**	3.3 E-7	8.0 E-8	<1.1 E-6**
Molybdenum	3.8 E-3*	6.6 E-6*	1.3 E-4	7.0 E-5*	2.6 E-5*	1.7 E-3*	5.6 E-5*	4.2 E-4*

(Continued)

TABLE 4-13. ELEMENTAL MASS FLOW RATES+

	LIGNITE (Flow Rate = 670 g/sec)	SERVICE WATER (Flow Rate = 2200 g/sec)	PRODUCT GAS AEROSOLS (Flow Rate = 9.0 g/sec)	PRODUCT GAS VAPORS (Flow Rate = 2300 g/sec) Acid/Base Impingers	PRODUCT GAS VAPORS (Flow Rate = 2300 g/sec) Persulfate Impingers	GASIFIER ASH (Flow Rate = 75 g/sec)	CYCLONE DUST (Flow Rate = 4 g/sec)	ASH PAN WATER (Flow Rate = 2200 g/sec)
Aluminum	4.0•	2.0E-4•	>1.3 E-3	LB•	1.2 E-2•	3.4•	9.2 E-2•	5.3 E-3•
Antimony	<3.4 E-4••	<6.6 E-6••	9.9 E-5	LB••	<2.4 E-5••	4.3 E-5••	2.4 E-6••	<6.6 E-6••
Arsenic	1.7 E-2••	2.2 E-6	>1.6 E-3	3.1 E-4••	3.9 E-4••	4.2 E-3••	2.5 E-4••	4.6 E-5••
Barium	2.7 E-1•	8.6 E-5	>1.2 E-3	LB•	1.5 E-4•	2.6 E-1•	6.8 E-3•	3.7 E-4•
Beryllium	2.0 E-4	<2.2 E-5	<3.0 E-6	<1.7 E-4	<3.6 E-5	2.3 E-5	2.8 E-6	<2.2 E-6
Bismuth	<1.3 E-4	<2.2 E-5	<1.1 E-5	<1.7 E-4	<3.6 E-5	<1.5 E-5	8.0 E-7	<2.2 E-6
Boron	2.5 E-2•	LB•	2.4 E-4	1.3 E-3•	LB•	8.2 E-3•	2.8 E-4•	5.7 E-3•
Bromine	1.3 E-3	2.2 E-4	2.4 E-5	LB	8.9 E-4	2.2 E-4	1.2 E-5	7.0 E-5
Cadmium	2.0 E-3	<2.2 E-5	<1.1 E-5	<1.7 E-4	<3.6 E-5	<1.5 E-5	<4 E-7	<2.2 E-6
Calcium	8.0•	2.1 E-2•	>2.5 E-3	1.2 E-3•	5.6 E-2•	7.2•	1.4 E-1•	2.0 E-1•
Cerium	3.4 E-3	6.6 E-5	8.2 E-5	<1.7 E4	LB	3.5 E-3	9.6 E-5	<8.1 E-6
Cesium	2.0 E-4	<2.2 E-5	<4.3 E-5	<1.7 E-4	1.2 E-4	1.5 E-4	1.2 E-5	<8.1 E-6
Chlorine	9.4 E-3	6.6 E-4	6.5 E-4	>5.6 E-1	>8.2 E-2	3.4 E-3	2.0 E-4	1.1 E-2
Chromium	3.3 E-3•	<2.2 E-6•	8.1 E-4	3.4 E-5•	9.9 E-5•	<1.5 E-5••	1.7 E-4•	<2.2 E-6•
Cobalt	1.7 E-3•	<1.3 E-5•	≤2.5 E-5•	5.6 E-5•	<5.1 E-5•	1.3 E-3•	3.5 E-5•	<1.3 E-5•
Copper	5.4 E-3•	7.3 E-5•	2.3 E-4	5.6 E-5•	<8.4 E-6•	3.3 E-3•	1.2 E-4•	1.3 E-5
Dysprosium	<1.3 E-4	<2.2 E-5	<7.4 E-6	<1.7 E-4	<3.6 E-5	1.5 E-4	1.6 E-5	<2.2 E-6
Erbium	<1.3 E-4	<2.2 E-5	<3.7 E-6	<1.7 E-4	<3.6 E-5	5.2 E-5	3.2 E-6	<2.2 E-6
Europium	2.0 E-4	<2.2 E-5	<3.9 E-6	<1.7 E-4	<3.6 E-5	7.5 E-5	4.0 E-6	<2.2 E-6
Fluorine	4.5 E-2	4.4 E-5	1.2 E-3	2.1 E-4	8.2 E-3	1.2 E-2	5.6 E-4	2.0 E-3
Gadolinium	≤2.7 E-4	<2.2 E-5	<7.4 E-6	<1.7 E-4	<3.6 E-5	1.5 E-4	8.0 E-6	<2.2 E-6
Gallium	1.3 E-3	2.2 E-5	6.5 E-5	2.0 E-4	LB	1.1 E-4	4.8 E-5	1.4 E-5
Germanium	<1.3 E-4	<2.2 E-5	1.2 E-4	<1.7 E-4	2.9 E-5	3.0 E4	8.0 E-6	<5.1 E-6
Gold	<1.3 E-4	<2.2 E-5	<2.9 E-6	<1.7 E-4	<3.6 E-5	<1.5 E-5	<4.0 E-7	<2.2 E-6
Hafnium	<1.3 E-4	<2.2 E-5	<5.0 E-6	<1.7 E-4	<3.6 E-5	≤1.5 E-4	2.0 E-6	<2.2 E-6
Holmium	<1.3 E-4	<2.2 E-5	<6.2 E-6	<1.7 E-4	<3.6 E-5	7.5 E-5	4.0 E-6	<2.2 E-6
Iodine	1.3 E-4	<2.2 E-6	<1.5 E-5	3.9 E-4	LB	3.0 E-5	3.6 E-6	1.1 E-5
Iridium	1.3 E-4	<2.2 E-5	<2.8 E-6	<1.7 E-4	<3.6 E-5	<1.5 E-5	<4.0 E-7	<2.2 E-6
Iron	1.0 E1•	4.4 E-4•	>1.2 E-3	5.1 E-4•	1.7 E-3•	4.2•	5.6 E-2•	4.2 E-3•
Lanthanum	1.3 E-3	1.1 E-4	1.1 E-4	<1.7 E-4	LB	3.5 E-3	9.6 E-5	<8.1 E-6
Lead	1.3 E-3	<2.2 E-5	9.0 E-4	LB	4.1 E-4	6.0 E-4	1.5 E-4	<2.9 E-6
Lithium	1.3 E-3	<2.2 E-5	1.7 E-5	7.7 E-5	1.2 E-4	4.5 E-4	4.0 E-5	<5.9 E-6
Lutetium	<1.3 E-4	<2.2 E-5	<3.8 E-6	<1.7 E-4	<3.6 E-5	<1.5 E-5	4.0 E-7	<2.2 E-6
Magnesium	2.0•	1.4 E-3•	>1.3 E-3	2.1 E-4•	4.6 E-4•	1.6•	3.8 E-2•	3.1 E-3•
Manganese	9.4 E-3•	4.6 E-5•	2.2 E-4	7.0 E-4•	3.4 E-5•	1.9 E-2•	2.7 E-4•	1.3 E-4•
Mercury	1.3 E-4	<1.1 E-6••	NR	3.4 E-6••	2.6 E-5••	3.3 E-7	8.0 E-8	<1.1 E-6••
Molybdenum	3.8 E-3•	6.6 E-6•	1.3 E-4	7.0 E-5•	2.6 E-5•	1.7 E-3•	5.6 E-5•	4.2 E-4•

(Continued)

TABLE 4-13. Continued

	LIGNITE (Flow Rate = 670 g/sec)	SERVICE WATER (Flow Rate = 2200 g/sec)	PRODUCT GAS AEROSOLS (Flow Rate = 9.0 g/sec)	PRODUCT GAS VAPORS (Flow Rate = 2300 g/sec) Acid/Base Impingers	Persulfate Impingers	GASIFIER ASH (Flow Rate = 75 g/sec)	CYCLONE DUST (Flow Rate = 4 g/sec)	ASH PAN WATER (Flow Rate = 2200 g/sec)
Neodymium	3.4 E-4	<2.2 E-5	<1.4 E-5	<1.7 E-4	<2.9 E-4	6.8 E-4	4.0 E-5	<2.2 E-6
Nickel	4.3 E-3•	2.2 E-6•	1.3 E-4	1.0 E-4•	1.2 E-4•	2.0 E-3•	8.0 E-5•	<1.0 E-5•
Niobium	1.3 E-3	≤2.2 E-5	<2.7 E-5	5.6 E-5	1.7 E-5	2.8 E-3	4.8 E-5	<4.4 E-6
Osmium	<1.3 E-4	<2.2 E-5	<2.9 E-6	<1.7 E-4	<3.6 E-5	<1.5 E-5	<4.0 E-7	<2.2 E-6
Palladium	<1.3 E-4	<2.2 E-5	<2.9 E-6	<1.7 E-4	<3.6 E-5	<1.5 E-5	<4.0 E-7	<2.2 E-6
Phophorus	>6.7 E-1	4.4 E-4	>1.4 E-3	1.7 E-2	8.7 E-3	>7.5 E-2	>4.0 E-3	9.2 E-4
Platinum	<1.3 E-4	<2.2 E-5	<2.9 E-6	<1.7 E-4	<3.6 E-5	<1.5 E-5	<4.0 E-7	<2.2 E-6
Potassium	7.4 E-1•	3.1 E-3•	>2.5 E-3	LB•	LB	5.2 E-1•	>4.0 E-3	1.3 E-1•
Praseodymium	2.7 E-4	<2.2 E-6	<8.6 E-4	<1.7 E-4	<9.4 E-5	3.0 E-4	2.0 E-5	<2.2 E-6
Rhenium	<1.3 E-4	<2.2 E-5	<2.9 E-6	<1.7 E-4	<3.6 E-5	<1.5 E-5	<4 E-7	<2.2 E-6
Rhodium	<1.3 E-4	<2.2 E-5	<2.9 E-6	<1.7 E-4	<3.7 E-5	<1.5 E-5	<4 E-7	<2.2 E-6
Rubidium	1.3 E-3	2.2 E-5	9.0 E-5	<5.6 E-5	4.3 E-5	1.2 E-3	1.2 E-4	3.1 E-4
Ruthenium	<1.3 E-4	<2.2 E-5	<2.9 E-6	<1.7 E-4	<3.6 E-5	<1.5 E-5	<4 E-7	<2.2 E-6
Samarium	6.7 E-4	<2.2 E-5	<1.2 E-5	<1.7 E-4	<3.6 E-5	3.8 E-4	1.6 E-5	<2.2 E-6
Scandium	3.4 E-4	2.2 E-5	<4.8 E-6	<1.7 E-4	<3.1 E-5	8.2 E-4	8 E-6	<2.2 E-6
Selenium	<3.4 E-4••	1.1 E-5••	<1.3 E-5	1.4 E-5••	2.4 E-4••	<7.5 E-5••	<4.8 E-6••	<1.5 E-5••
Silicon	>6.7 E-1	8.8 E-3	>6.6 E-3	LB	>6.0 E-2	>7.5 E-2	>4.0 E-3	>8.8 E-3
Silver	≤5.4 E-4	<2.2 E-5	8.8 E-5	<1.7 E-4	Contaminated	2.2 E-4	<4.0 E-7	3.1 E-5
Sodium	2.3•	1.4 E-2•	>5.7 E-3	1.9 E-3•	6.3 E-3•	1.8•	>4.8 E-2•	1.2•
Strontium	5.1 E-1	4.4 E-4	>1.2 E-3	LB	5.8 E-4	>7.5 E-2	>4.0 E-3	>1.2 E-2
Sulfur	>6.7 E-1	2.2 E-3	>2.6 E-3	3.6 E-1	3.9+	1.23•••	6.8 E-2•••	>1.5 E-2
Tantalum	<1.3 E-4	<2.2 E-5	<5.0 E-6	<1.5 E-3	<3.6 E-5	<1.5 E-5	<4.0 E-7	<2.2 E-6
Tellurium	<1.3 E-4	<2.2 E-5	<2.9 E-6	3.4 E-4	LB	<2.2 E-5	8.0 E-7	<2.9 E-6
Terbium	<1.3 E-4	<2.2 E-5	<5.0 E-6	<1.7 E-4	<3.6 E-5	7.5 E-5	8.0 E-6	<2.2 E-6
Thallium	<1.3 E-4	<2.2 E-4	<7.4 E-6	<1.7 E-4	<3.6 E-5	<1.5 E-5	4.0 E-6	<2.2 E-6
Thorium	2.7 E-3	<2.2 E-4	<2.2 E-5	<1.7 E-3	2.6 E-4	1.3 E-3	1.6 E-5	<1.2 E-5
Thulium	<1.3 E-4	<2.2 E-5	<2.9 E-6	<1.7 E-4	<3.6 E-5	1.5 E-5	4.0 E-7	<2.2 E-6
Tin	≤2.7 E-4	<2.2 E-5	7.6 E-5	<1.7 E-4	<3.6 E-5	1.5 E-4	3.2 E-6	<2.2 E-6
Titanium	1.8 E-1•	<1.1 E-5•	>1.3 E-3	<5.6 E-5•	<4.1 E-5•	1.6 E-1•	4.8 E-3	<4.2 E-5•
Tungsten	<1.3 E-4	4.4 E-5	<2.6 E-5	<3.9 E-4	<3.6 E-5	1.5 E-4	8.0 E-6	2.4 E-5
Uranium	2.0 E-3	<2.0 E-4	<1.2 E-5	<4.1 E-4	<2.0 E-4	4.5 E-4	1.2 E-5	<8.8 E-6
Vanadium	1.0 E-2•	<6.6 E-6•	7.9 E-5	5.6 E-5•	<2.4 E-5•	6.8 E-3•	2.2 E-4	<6.6 E-6•
Ytterbium	<1.3 E-4	<2.2 E-5	<7.4 E-6	<1.7 E-4	<3.6 E-5	7.5 E-5	3.6 E-6	<2.2 E-6
Yttrium	2.0 E-3	<2.2 E-5	3.5 E-5	<1.7 E-4	8.7 E-6	4.5 E-3	2.8 E-5	<2.9 E-6
Zinc	5.8 E-3•	<6.6 E-6•	>1.4 E-3	4.6 E-4•	1.3 E-4•	2.8 E-3•	2.8 E-4	<1.1 E-5•
Zirconium	8.0 E-3	≤4.4 E-5	6.8 E-5	1.2 E-4	LB	1.2 E-2	2.4 E-4	<1.5 E-5

+Flow rates in g/sec.

•ICPES.

••AAS, all other values determined by SSMS.

•••Ultimate analysis, plus process GC's, all other values determined by SSMS.

NR = Not Reported.

LB = Value less than or equal to blank value.

TABLE 4-14. PERCENT DISTRIBUTION OF MINOR AND TRACE ELEMENTS[a] IN THE DISCHARGE STREAMS

	Product Gas Aerosols	Product Gas Vapors[+]	Gasifier Ash:	Cyclone Dust	Ash Pan Water
Aluminum	> 0.04	0.3	96.8	2.6	0.2
Antimony	56.6	<13.7	24.6	1.4	<3.8
Arsenic	>24.7	6.0	64.8	3.9	0.7
Barium	> 0.5	0.06	96.8	2.5	0.1
Beryllium	< 4.5	<53.7	>34.3	>4.2	<3.3
Bismuth	<16.9	<55.4	<23.1	1.2	<3.4
Boron	1.5	8.3	52.2	1.8	36.3
Bromine	2.0	73.2	18.1	1.0	5.8
Calcium	> 0.03	0.7	94.8	1.8	2.6
Cerium	2.1	< 4.4	90.8	2.5	0.2
Cesium	12.9	36.0	45.0	3.6	2.4
Chlorine	0.7	>84.3	3.5	0.2	11.3
Chromium	73.9	9.0	< 1.4	15.5	<0.2
Cobalt	< 1.8	< 3.6	91.3	2.5	<0.9
Copper	6.3	< 0.3	89.9	3.3	0.4
Dysprosium	< 3.5	<17.0	>70.9	>7.6	>1.0
Erbium	< 3.8	<37.1	>53.6	>3.3	<2.3
Europium	< 3.2	<29.7	>61.9	>3.3	<1.8
Fluorine	5.0	34.2	50.1	2.3	8.3
Gadolinium	< 3.6	<17.7	>73.7	>3.9	<1.1
Gallium	14.9	45.8	25.2	11.0	3.2
Germanium	26.0	6.3	64.9	1.7	<1.1
Hafnium	< 2.6	<18.4	<76.8	>1.0	<1.1
Holmium	< 5.0	<29.2	>60.8	>3.2	<1.8
Iodine	< 3.3	86.7	6.7	0.8	2.4
Iron	> 0.03	0.04	98.5	1.3	0.1
Lanthanum	2.8	< 4.4	90.1	2.5	<0.2
Lead	43.6	19.9	29.1	7.3	<0.1
Lithium	2.7	19.0	71.1	6.3	<0.9
Lutetium	< 6.6	<62.7	<26.1	0.7	<3.8
Magnesium	> 0.08	0.03	97.4	2.3	0.2
Manganese	1.1	0.2	96.7	1.4	0.7
Mercury	NR	94.5	1.2	1.5	<4.0
Molybdenum	5.6	1.1	72.9	2.4	18.0

(Continued)

TABLE 4-14. Continued

	Product Gas Aerosols	Product Gas Vapors†	Gasifier Ash:	Cyclone Dust	Ash Pan Water
Neodymium	< 1.4	<28.3	>66.3	3.9	< 0.2
Nickel	5.6	5.1	85.5	3.4	< 0.4
Niobium	< 0.9	0.6	96.7	1.7	< 0.2
Phosphorus	> 1.6	9.7	>83.3	>4.4	1.0
Potassium	> 0.4	LB	79.2	>0.6	19.8
Praeseodymium	< 2.0	<22.1	>70.6	4.7	< 0.5
Rubidium	5.1	2.4	68.1	6.8	17.6
Samarium	< 2.7	< 8.1	85.2	3.6	< 0.5
Scandium	< 0.6	< 3.6	94.7	0.9	< 0.3
Selenium	< 3.7	>69.0	<21.6	<1.4	< 4.3
Silver*	17.3	<33.4	>43.2	<0.08	> 6.1
Sodium	> 0.2	0.2	58.8	1.6	39.2
Strontium	> 1.3	0.6	>80.8	>4.3	>12.9
Sulfur	> 0.05	74.8	23.6	1.3	> 0.3
Tellurium	< 0.8	92.2	< 6.0	0.2	< 0.8
Terbium	< 4.0	<28.5	>59.4	>6.3	< 1.7
Thallium	<11.5	<55.7	<23.2	6.2	< 3.4
Thorium	< 1.4	16.1	80.7	1.0	< 0.7
Thulium	< 5.1	<63.7	>26.5	0.7	< 3.9
Tin	>28.4	<13.5	>56.1	>1.2	< 0.8
Titanium	> 0.8	< 0.02	96.3	2.9	< 0.03
Tungsten	<10.7	<14.8	61.5	3.3	9.8
Uranium	< 1.8	<29.3	>65.9	1.8	< 1.3
Vanadium	1.1	< 0.3	95.4	3.1	< 0.09
Yttorbium	< 6.0	<29.0	>60.4	2.9	< 1.8
Yttrium	0.8	0.2	98.4	0.6	< 0.06
Zinc	>30.3	2.8	60.6	6.1	< 0.2
Zirconium	0.5	1.0	96.4	1.9	< 0.1

[a] Elemental concentrations were below the detection limit for cadmium, gold, iridium, osmium, palladium, platinum, rhenium, rhodium, ruthenium, and tantalum.

†Elemental concentrations determined using $AgNO_3$-$(NH_4)_2S_2O_8$ impinger collection.

*Elemental concentration determined using acid/base impinger collection due to contamination or less than blank values of $AgNO_3$-$(NH_4)_2S_2O_8$ impingers.

aluminum
barium
boron
calcium
cerium
cobalt
copper
gadolinium
hafnium
iron
lanthanum
lithium
lutetium
magnesium
manganese
molybdenum
nickel
niobium
phosphorus
potassium
rubidium
samarium
scandium
sodium
strontium
thorium
thulium
titanium
tungsten
vanadium
zirconium

The sensitivity of the analytical techniques precluded drawing definite conclusions about the behavior of some of the elements. The following elements will require additional data to definitively characterize their behavior:

beryllium
bismuth
cadmium
dysprosium
erbium
europium
holmium
iridium
neodymium
osmium
palladium
platinum
praeseodymium
rhodium
ruthenium
silver
tantalum
terbium
thallium
uranium
ytterbium

The element distributions in the discharge streams are displayed graphically in Figure 4-7 in the order of ascending elemental boiling points. There is a general trend of higher elemental distribution in the product gas for elements with lower boiling points, shifting to a higher elemental distribution in the gasifier ash for elements with higher boiling points. Although a general trend is evident, a direct correlation between elemental boiling point and distribution is neither expected nor found. Elemental behavior is dependent not only on elemental boiling point, but also on much more complex properties such as chemical reactions in the gasifier, volatility of compounds containing the elements and solubility of elements and compounds in the tars and oils.

4.3.3 Elemental Enrichment Ratios

An alternate approach to evaluating trends of elemental behavior in the gasification of coal is through examination of the elemental concentrations in the solids (gasifier ash and cyclone dust) relative to the original concentrations in the coal. Elemental enrichment ratios were calculated for each element in the gasifier ash and cyclone dust using the following equation:

$$\text{Elemental Enrichment Ratio} = \frac{\text{Concentration of Element in Solid Waste Stream}}{\text{Concentration of Element in Lignite}}$$

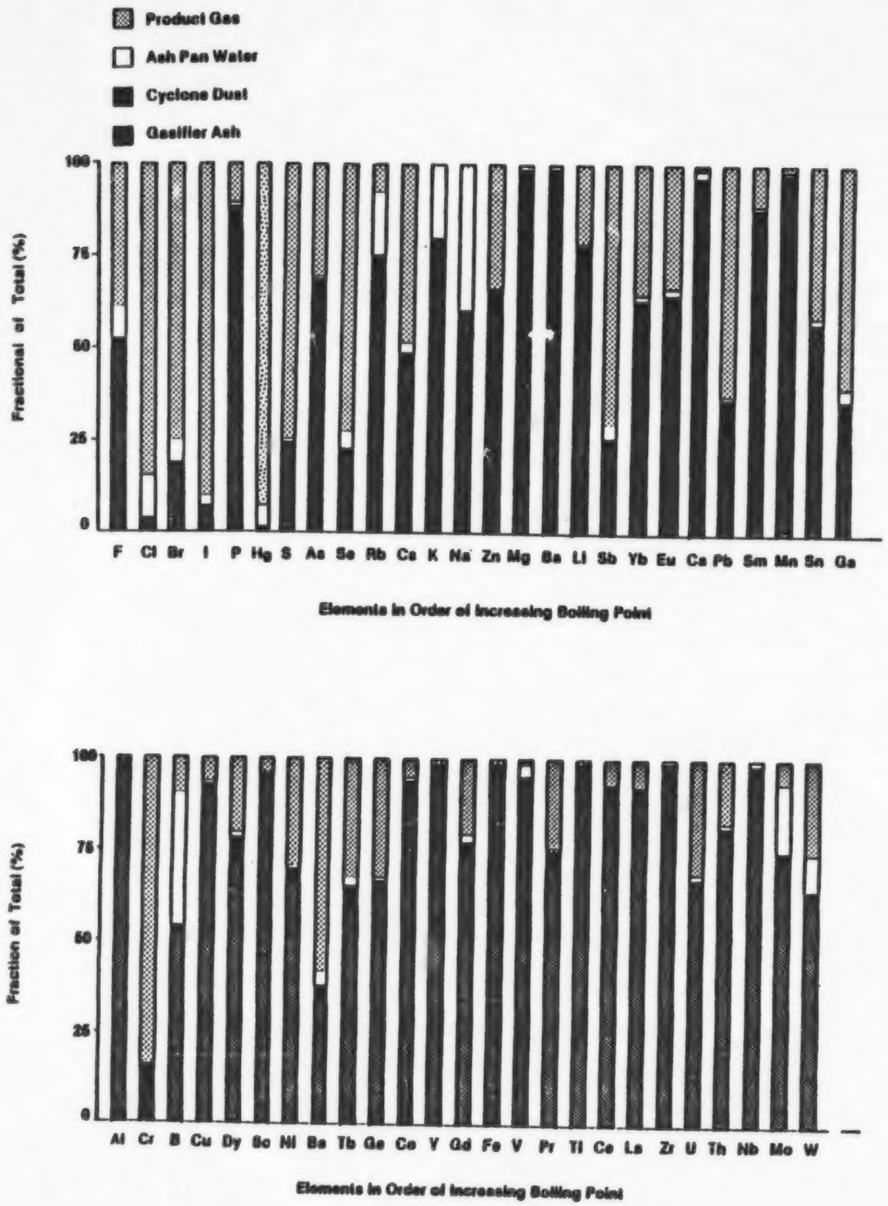

Figure 4-7. Stream Elemental Distributions or Percentage of Combined Discharge Streams

Table 4-15 presents the elemental enrichment ratios. Figures 4-8 through 4-11 depict these data graphically in order of ascending boiling points.

During gasifier operation, the lignite is reduced to ash material due to the loss of carbonaceous and volatile components. The concentration of some elements is increased simply because of this loss of mass. The contribution of this loss to increases in elemental concentration or enrichment can be estimated by calculating enrichment ratios from the ash contents of the gasifier ash and cyclone dust. The original lignite ash content averaged 12.1 percent. The gasifier ash had an average ash content of over 62 percent and was the bulk of the ash discharge. The cyclone dust consisted of unreacted or partially reacted, relatively small carbonaceous particulate with an average ash content of approximately 40 percent. The ash residue enrichment ratios are shown as horizontal lines in Figures 4-8 through 4-11.

If the enrichment ratio of an element is greater than the ash residue enrichment ratio for that stream, elemental enrichment is indicated. Conversely, if the enrichment ratio of an element is less than the ash residue enrichment ratio for that stream, elemental depletion is indicated.

Elements whose enrichment ratios are close in value to those of the ash residue are assumed to be nonvolatile. These elements are distributed among the discharge streams along with the ash. The concentrations of such elements in the lignite feedstock are therefore primarily the result of a loss of mass during gasification.

Other elements in the lignite feed, however, are volatile and are vaporized during gasification. These volatilized elements either remain gaseous, condense partially, or condense completely.

Most of the elements which were judged to be highly volatile from their distribution in the discharge streams are found to be depleted in both the gasifier ash and cyclone dust. Notable exceptions are cesium and gallium which, contrary to expectations, are enriched in both solids; this behavior is more characteristic of nonvolatile elements.

The elements judged to be moderately volatile from distributions fall into two major categories. Lead, chromium, and zinc follow the expected behavior of being depleted in the gasifier ash and enriched in the cyclone dust. On the other hand, arsenic and antimony are depleted in both solids. The distribution results have shown that both of these elements were found in the aerosol portion of the product gas, indicating somewhat greater volatility than for the other moderately volatile elements. Germanium is enriched in both solids, and the enrichment ratios for tin are very close to the ash contents. The behavior of both of these is, therefore, more characteristic of nonvolatile elements.

The enrichment ratios also provide an indication of behavior for some of those elements for which analytical detection limitations precluded drawing conclusions from the distributions. Beryllium, bismuth, cadmium, silver, gold,

TABLE 4-15. ELEMENTAL ENRICHMENT RATIOS FOR GASIFIER ASH AND CYCLONE DUST

	Gasifier Ash[1]	Cyclone Dust[1]
Ash	5.6	3.3
Aluminum	6.9	4.0
Antimony	1.7	1.2
Arsenic	2.5	2.7
Barium	7.7	4.0
Beryllium	3.3	1.1
Bismuth	1.7	>1.3
Boron	2.9	2.0
Bromine	3.3	2.0
Cadmium	<1.0	<0.03
Calcium	8.0	2.9
Cerium	9.9	5.3
Chlorine	2.6	3.1
Chromium	<0.06	13.2
Cobalt	6.3	3.6
Copper	5.7	3.9
Dysprosium	>16.7	>26.7
Erbium	>5.7	>5.3
Europium	>10.0	>4.0
Fluorine	7.4	3.1
Gadolinium	>12.0	>8.0
Gallium	10.5	6.0
Germanium	>36.7	>13.3
Gold	1.2	0.5
Hafnium	7.7	>3.3
Holmium	>10.0	>6.7
Iodine	1.6	2.0
Iridium	1.7	0.7
Iron	2.9	0.8
Lanthanum	15.3	8.0
Lead	2.8	14.8
Lithium	17.9	6.9
Lutetium	1.7	0.7
Magnesium	7.2	3.2
Manganese	17.7	5.2
Mercury	0.0034	0.013
Molybdenum	4.2	2.7
Neodymium	20.8	16.7
Nickel	4.5	3.9
Niobium	18.0	6.0
Osmium	1.7	0.7

(Continued)

TABLE 4-15. Continued

	Gasifier Ash[1]	Cyclone Dust[1]
Palladium	1.7	0.7
Phosphorous	>1.7	1.7
Platinum	1.7	0.7
Potassium	5.9	4.6
Praeseodymium	30.0	14.3
Rhenium	1.7	0.7
Rhodium	1.7	0.7
Rubidium	14.7	20.7
Ruthenium	1.7	0.7
Samarium	12.2	4.4
Scandium	12.0	1.6
Selenium	2.0	2.4
Silicon	1	1
Silver	0.9	0.03
Sodium	6.6	3.4
Strontium	>1.1	>1.1
Sulfur*	1.5	1.5
Tantalum	1.7	0.7
Tellurium	2.6	0.8
Terbium	>16.7	>13.3
Thallium	1.7	>6.7
Thorium	7.4	1.1
Thulium	2.0	0.7
Tin	>6.0	>3.2
Titanium	6.7	4.0
Tungsten	16.7	13.3
Uranium	15.5	1.2
Vanadium	6.2	4.3
Ytterbium	>13.3	>6.0
Yttrium	13.5	1.8
Zinc	3.9	8.4
Zirconium	20.6	3.3

*Determined using ultimate analyses.

[1] Elemental Enrichment Ratio = $\frac{\text{Concentration of Element in Solid Waste System}}{\text{Concentration of Element in Lignite}}$

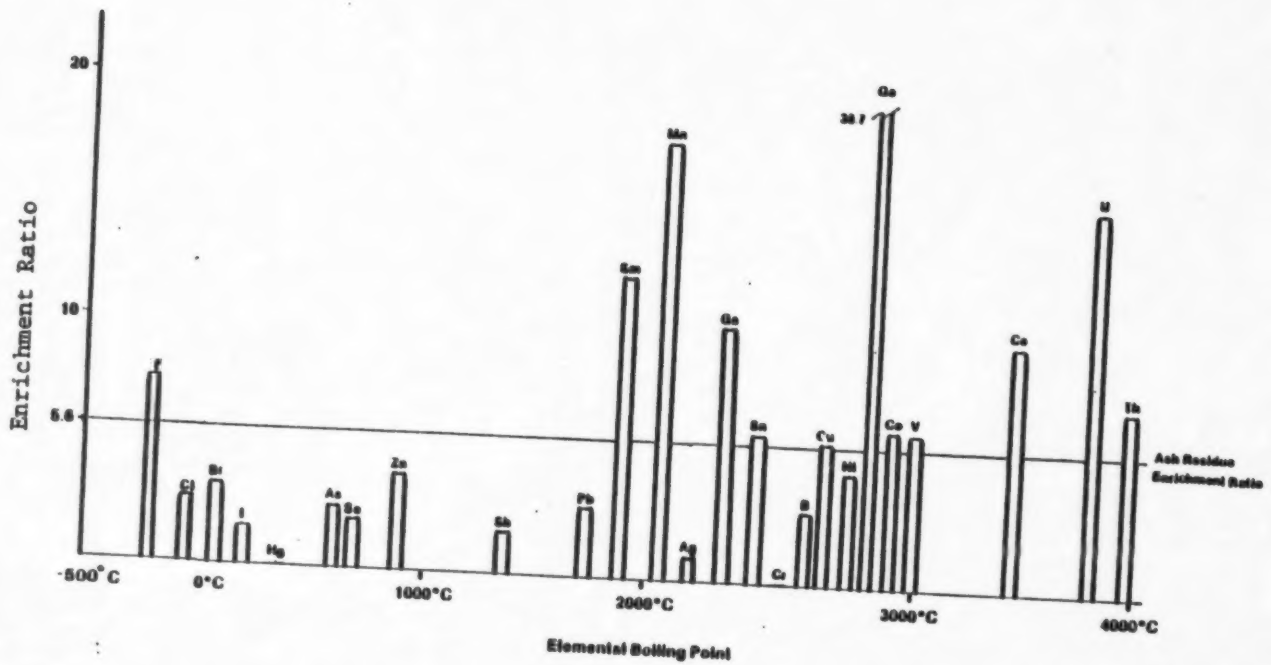

Figure 4-8. Elemental Enrichment Ratios of Trace Elements in Gasifier Ash

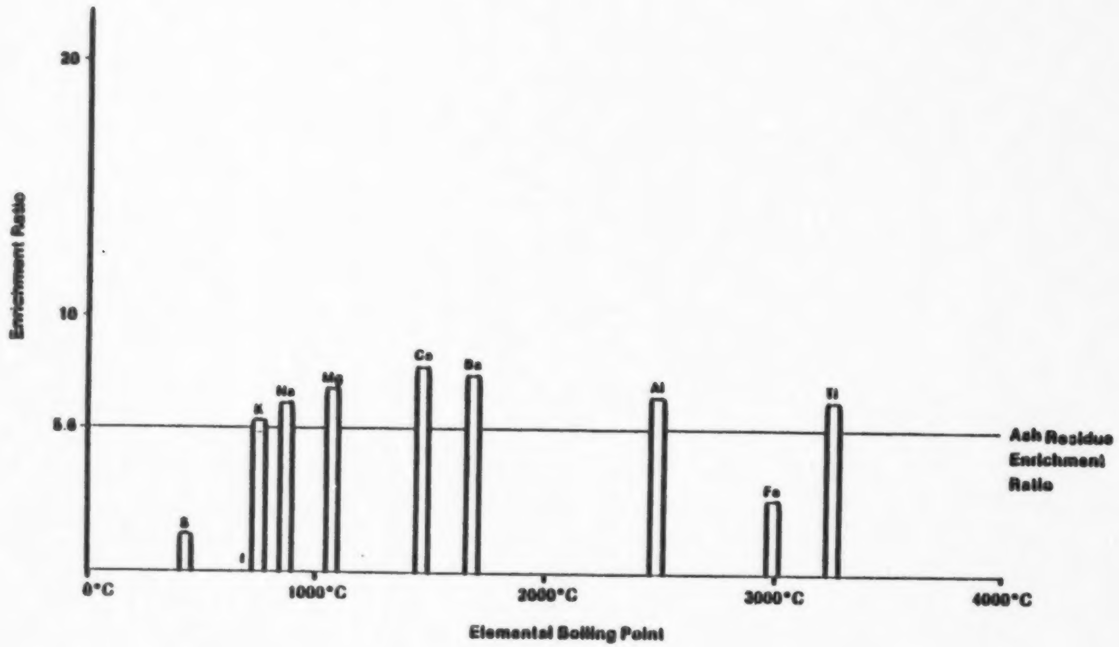

Figure 4-9. Elemental Enrichment Ratios of Minor Elements in Gasifier Ash

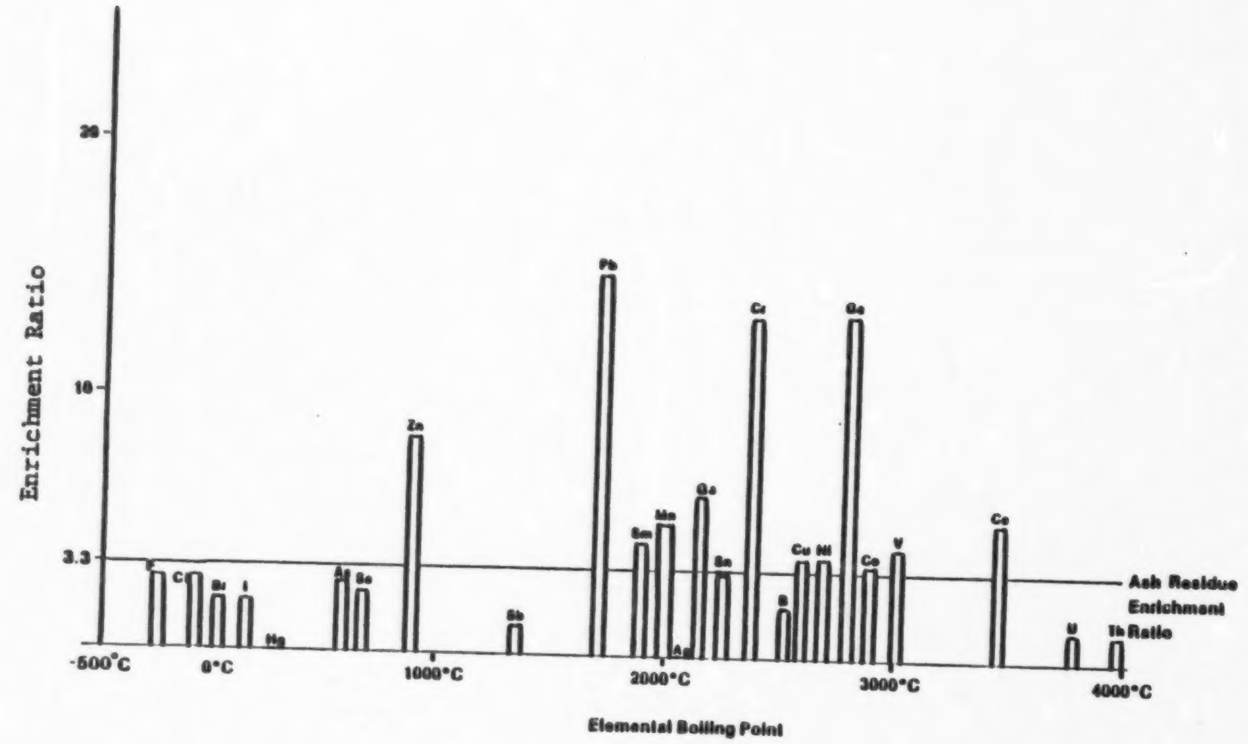

Figure 4-10. Elemental Enrichment Ratios of Trace Elements in Cyclone Dust

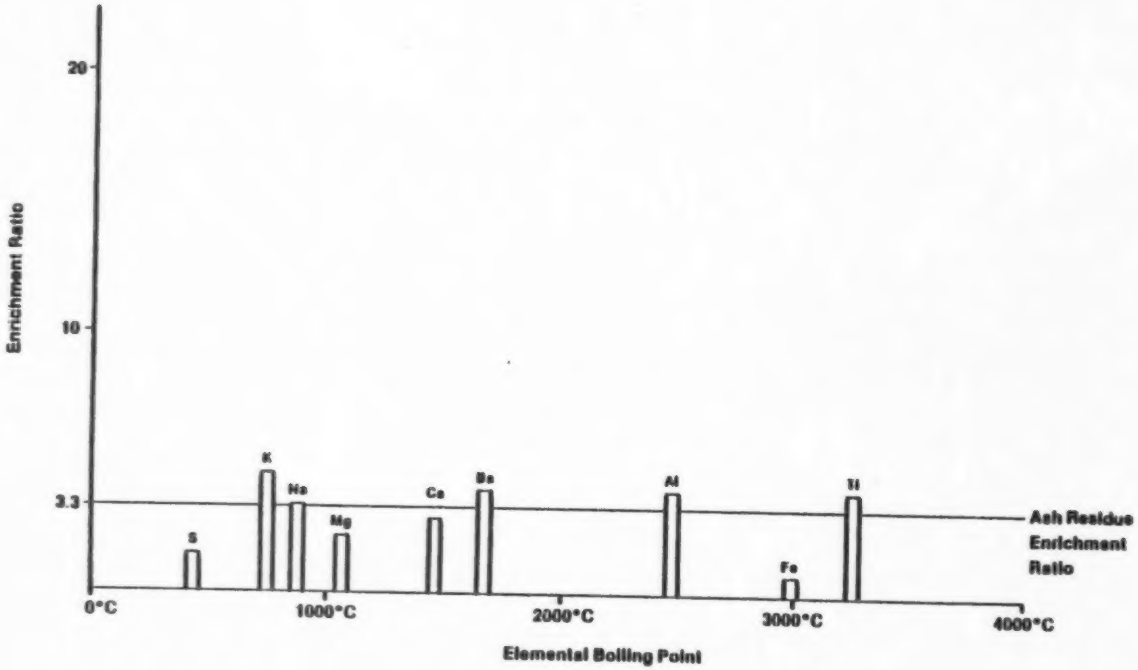

Figure 4-11. Elemental Enrichment Ratios of Minor Elements in Cyclone Dust

and thalium are depleted in both solids; this is characteristic of volatile behavior. Uranium is enriched in the gasifier ash and depleted in the cyclone dust which is indicative of nonvolatile behavior.

4.3.4 Impact of Trace Elements on Water Quality Due to Leaching

While there is considerable concern about elemental concentrations in the product gas because of the atmospheric emission of these elements after combustion, there is equal concern about the ultimate fate of trace elements in solid wastes. Gasifier ash accounts for more than 50 percent of the elemental discharges of 29 of the 73 elements listed in Table 4-14.

Regulations promulgated by the EPA in response to RCRA provide an extraction procedure with allowable concentration limits of contaminants (eight trace elements, four pesticides and two herbicides) for solid wastes to be listed as non-hazardous. Different handling and disposal methods are prescribed for hazardous and non-hazardous wastes.

The gasifier ash and cyclone dust were subjected to the RCRA extraction protocol and analyzed for the fourteen contaminants. According to the results of the RCRA leaching protocol, the gasifier ash and cyclone dust are non-hazardous wastes. Table 4-16 presents the RCRA extraction contaminant limits and the related concentrations of the gasifier ash and cyclone dust RCRA leachates.

TABLE 4-16. COMPARISON OF SOLID EFFLUENT EXTRACTS AND RCRA EXTRACT LIMITS

	RCRA Extract Limits+ (5/19/80)	Gasifier Ash Leachate+	Cyclone Dust Leachate+
As	5,000	33	4
Ba	100,000	680	390
Cd	1,000	<0.5	<0.5
Cr	5,000	<1	<1
Pb	5,000	<2	<2
Hg	200	<0.5	<0.5
Se	1,000	6	2
Ag	5,000	<0.5	<0.5
Endrin	20	<2.0	<2.0
Lindane	400	<0.2	<0.2
Methoxychlor	10,000	<2.0	<2.0
Toxaphene	500	<100	<100
2,4-D	10,000	<0.8	<0.8
2,4,5-TP Silvex	1,000	<0.3	<0.3

+Concentrations in μg/liter.

The ash pan water, ash pan carry-over water*, and service water were analyzed for minor and trace elements by SSMS (Tables F-40 through F-44), ICPES (Table F-58), and AAS (Table F-61) and wastewater parameters (Table F-63). The data were compared to National Interim Primary Drinking Water Regulations (NIPDWR, Ref. 9) and National Secondary Drinking Water Regulations (NSDWR, Ref. 10). Only one stream exceeded the NIPDWR. The ash pan carry-over water had a concentration of 300 μg/l of lead compared to the standard of 50 μg/l. Ash pan water exceeds NSDWR for iron, manganese, sulfate, pH, and TDS. The ash pan carry-over water exceeds NSDWR for iron and pH. It must be noted that these comparisons are between the characteristics of a process wastewater and drinking water standards. The impact of parameters exceeding the drinking water standards would be lessened upon dilution of the wastewater in a receiving water stream as well as by other factors specific to a given site. Also, it should be noted that the service water entering the ash pan exceeds NSDWR for iron and is relatively high in manganese. Therefore, the levels of these two elements cannot necessarily be attributed to the process. The data presentation is in Table 4-17.

Potential water pollution problems resulting from solid wastes of gasification processes are the result of solids dissolution in process waters (i.e., ash pan water, sluice water, quench water) or from water run-off from the solids disposal. The RCRA extraction protocol addresses the potential contamination of surface and groundwater due to leaching of disposed solids. The analyses of contaminants required by RCRA protocol are presented in Table 4-16. However, as in the case of the gasifier ash, the material extracted by RCRA protocol may not be the total amount soluble. Since the gasifier ash had been in contact with the ash pan water, trace element (and anion) concentrations in the ash pan water are most probably due to leaching of the gasifier ash. As a means of estimating the total soluble trace elements of the gasifier ash, the amount of trace elements leached by RCRA protocol and the ash pan water were related to the total trace element concentration using the following equations:

$$(1) \quad \text{Percent Soluble} = \frac{\text{Total Soluble}}{\text{Total Element}} \times 100$$

$$(2) \quad \text{Total Element} = A + B$$

$$(3) \quad \text{Total Soluble} = B + C$$

where A = elemental concentration in μg/g in gasifier ash

B = elemental concentration in μg/l in ash pan water x $\left[\frac{\text{ash pan water flow rate (l/s)}}{\text{gasifier ash flow rate (g/s)}}\right]$

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*Ash pan carry-over water is the water discharged with gasifier ash during "plowing". The elemental concentrations of this stream were investigated to determine if trace element concentrations were higher in this stream than in the ash pan water due to the turbulence caused by the "plowing".

TABLE 4-17. COMPARISON OF LIQUID STREAMS TO DRINKING WATER STANDARDS[1]

	NIPDWS** µg/l	NSDWR*** µg/l	ASH PAN WATER* RANGE µg/l	ASH PAN WATER* AVERAGE µg/l	ASH PAN CARRY-OVER WATER µg/l	SERVICE WATER[2] µg/l
As	50		11 - 30+	21+	9+	<10
Ba	1,000		91 - 230	170	250	100
Cd	10			<1	≤10	<10
Cl⁻		250,000	48,000 - 110,000	78,000	2,000	300
Cr	50			<1	<1	≤30
Cu		1,000	3 - 10	6	<1	70
F⁻	1,800		300 - 710	530	~1,000	~20
Fe		300	540 - 3,400	1,900	910	3,000
Pb	50		<1 - 2	<1.3	300	<10
Mn		50	27 - 96	58	11	40
Hg	2			<0.5+	<0.5+	
Se	10		<5 - 10+	<7	<5+	<10
Ag	50		2 - 30	14	20	<10
Zn		5,000	<3 - 12	<5.3	<3	80
NO_3^- (as N)		10,000		<20		
$SO_4^=$ (mg/l)		250	540 - 1,870	1,260		6.1
pH		6.5 - 8.5	10.2 - 11.3	10.8	5.0	4.3
TDS (mg/l)		500	1,250 - 3,050	2,250		52

[1] Elemental analytical results performed by ICPES unless noted otherwise.

[2] Elemental analytical results performed by SSMS.

*Samples RM-18, RM-23, RM-49.

**National Interim Primary Drinking Water Standards (Federal Register, 8/27/80).

***National Secondary Drinking Water Regulations (Federal Register, 7/19/79).

+Analysis performed by AAS.

$$C = \text{elemental concentration in RCRA leachate} \times \left[\frac{\text{leachate volume (2l)}}{\text{gasifier ash mass (100 g)}}\right]$$

The total soluble trace element concentration of the cyclone dust was also estimated. However, the cyclone dust was not in contact with water in the process, so elemental concentrations in the cyclone dust (Total Element) were directly related to RCRA leachate trace element concentrations (Total Soluble).

The "Percent Soluble" trace elements of the gasifier ash and cyclone dust compare very similarly for trace elements not affected by analytical values outside of instrumental detection limits. The results of the evaluation of the total soluble material of the gasifier ash and cyclone dust are presented in Table 4-18. Preleaching of the gasifier ash by the ash pan water did not significantly affect the RCRA leaching results. The elements exhibit very similar solubility characteristics in both the gasifier ash and cyclone dust. Most elements in both solids are relatively insoluble with only the following seven (of those for which analytical detection limits did not significantly impact the data) having more than 25% soluble in either solid:

boron
bromine
chlorine
molybdenum
potassium
selenium
sodium

4.4 Extractable Organics Results

The organic character of the five discharge streams was determined to provide environmental and process data. The analytical matrix followed for organic characterization included:

- TCO and GRAV analyses to determine the total organic loading,
- LC separations of the samples to provide information describing general chemical character,
- IR analyses to further identify chemical character,
- gas chromatographic analyses using a Hall electrolytic conductivity detector for quantitation of halogen-, sulfur-, and nitrogen-containing organic compounds, and
- gas chromatographic mass spectrometric analysis for quantitation of specific organic compounds.

The total organic loading of each of the five discharge streams and the service water was determined by summing total chromatographable organics (TCO) and gravimetric (GRAV) analyses. The total organic loading data indicate the merit of additional analyses. The total organic loading data are presented

TABLE 4-18. GASIFIER ASH AND CYCLONE DUST ELEMENTS AND THEIR SOLUBILITIES

	Gasifier Ash			Cyclone Dust		
	Total Element	Total Soluble	Percent Soluble	Total Element	Total Soluble	Percent Soluble
Aluminum*	40,000	70	0.18	23,000	200	0.87
Antimony	<0.92	<0.13	14	0.60	0.10	17
Arsenic*	59	1.3	2.2	63	0.06	0.10
Barium*	3,300	19	0.58	1,700	6	0.35
Beryllium	2.2	<0.07	3.2	0.70	<0.04	5.7
Bismuth	<0.28	<0.07	25	0.20	<0.04	20
Boron*	180	160	89	69	78	>100
Bromine*	5.9	0.94	16	3	6.6	>100
Cadmium*	<3.1	<0.04	1.3	<0.10	<0.01	10
Calcium*	99,000	31,000	31	35,000	12,000	34
Cerium	45	<0.15	0.33	24	<0.04	0.17
Cesium	<2.1	<0.15	7.1	3	<0.04	1.3
Chlorine*	180	140	78	51	76	>100
Chromium	<0.23	<0.05	22	43	<0.02	0.05
Cobalt	15.7	<0.30	1.9	8.8	0.72	8.2
Copper*	43	0.20	0.47	29	0.98	3.4
Dysprosium	2.5	<0.07	2.8	4	<0.04	1.0
Erbium	0.88	<0.07	8.0	0.80	<0.04	5
Europium	2.5	<0.07	2.8	1	<0.04	4
Fluorine*	360	27	7.5	140	3.4	2.4
Gadolinium	3.0	<0.07	2.3	2	<0.04	2
Gallium	21	0.18	0.86	12	–	–
Germanium	5.6	0.11	2.0	2	<0.04	2
Gold	<2.5	<0.07	2.8	<0.1	<0.04	40
Hafnium	<1.2	<0.07	5.8	0.50	<0.04	8
Holmium	1.5	<0.07	4.7	1	<0.04	4
Iodine	0.85	<0.19	22	0.90	0.18	20
Iridium	<0.28	<0.07	25	<0.1	<0.04	40
Iron*	51,000	56	0.11	14,000	0.48	0.003
Lanthanum	46	<0.15	0.33	24	<0.04	0.17
Lead	7	<0.08	1.1	37	<0.04	0.11
Lithium	26	<0.12	0.46	10	0.18	1.8
Lutetium	<0.28	<0.07	25	0.10	<0.04	40
Magnesium	22,000	520	2.4	9,600	82	0.85
Manganese*	230	1.8	0.78	67	0.20	0.30
Mercury	<0.015	<0.025	>100	0.02	<0.01	50
Molybdenum*	27	6.7	25	14	2.2	16
Neodymium	12.5	<0.07	0.56	10	<0.04	0.4
Nickel	23	<0.54	2.3	20	1.3	6.5
Niobium	36	<0.10	0.28	12	<0.04	0.33
Osmium	<0.28	<0.07	25	<0.10	<0.04	40

(Continued)

TABLE 4-18. Continued

	Gasifier Ash			Cyclone Dust		
	Total Element	Total Soluble	Percent Soluble	Total Element	Total Soluble	Percent Soluble
Palladium	<0.28	<0.07	25	<0.10	<0.04	40
Phosphorus	>1,000	12	1.2	>1,000	–	–
Platinum	<0.28	<0.07	25	<0.10	<0.04	40
Potassium*	7,400	2,100	28	4,400	<0.04	4.5
Praseodymium	11	<0.07	0.64	5	<0.04	0.8
Rhenum	<0.28	<0.07	25	<0.10	<0.04	40
Rhodium	<0.28	<0.07	25	<0.10	<0.04	40
Rubidium*	26	4.5	17	31	0.4	1.3
Ruthenium	<0.28	<0.07	25	<0.10	<0.04	40
Samarium	11	<0.07	0.64	4	<0.04	1
Scandium	15	<0.09	0.60	2	<0.04	2
Selenium	<1.2	<0.33	28	1.2	0.02	1.7
Silicon	>1,100	>240	22	>1,000	4.8	0.48
Silver	<3.4.	<0.42	12	<0.10	<0.01	10
Sodium	40,000	20,000	50	12,000	4,600	38
Strontium	>1,200	>350	29	>1,000	>200	20
Sulfur	>1,200	>400	33	>1,000	>200	20
Tantalum	<0.28	<0.07	25	<0.10	<0.04	40
Tellurium	<0.69	<0.08	12	0.20	<0.04	20
Terbium	2.5	<0.07	2.8	2	<0.04	2.0
Thallium	<0.28	<0.07	25	1	<0.04	4.0
Thorium	26	<0.56	2.2	4	<0.4	10
Thulium	0.30	<0.07	23	0.10	<0.04	40
Tin	1.5	<0.07	4.7	0.80	<0.04	5.0
Titanium*	2,000	8.9	0.44	1,200	2.8	0.23
Tungsten	2.8	<0.36	13	2	<0.04	2
Uranium	16	0.52	3.2	3	<0.20	6.7
Vanadium*	81	1.6	2.0	56	2.0	3.6
Ytterbium	2.0	<0.07	3.5	0.90	<0.04	4.4
Yttrium*	54	0.24	0.44	7	0.12	1.7
Zinc*	34	0.94	3.1	71	0.38	0.54
Zirconium	180	0.25	0.14	59	<0.06	.10

*No elemental concentrations outside of instrumental detection limits.

in Table 4-19 for the five discharge streams. The organic loading of the service water, 530 μg/l (1.1 x 10^3 μg/s), showed that the contribution of organic material to the process by the service water was insignificant and no further characterization was necessary.

The organic loading data presented in Table 4-19 were determined on composite samples. The basis for forming the composite samples was TCO and GRAV analyses performed on the individual components of each sample. The screening data are presented in Section F.2.1 of Appendix F. The concentration units and phases of the streams vary and do not allow direct correlation of results. However, the mass flow of extractable organics presented with the organic loading data indicates that the vast majority (99.8%) of extractable organic material leaves the gasifier in the product gas.

TABLE 4-19. ORGANIC LOADING OF DISCHARGE STREAMS

	Extractable Organics	
	Concentration	Mass Flow
Product Gas Aerosols	8.8 E5 μg/g (3.3 E6 μg/Nm^3)	8.0 g/s
Product Gas Vapors	5.8 E6 μg/Nm^3	14.0 g/s
Gasifier Ash	2.4 E2 μg/g	1.8 E-2 g/s
Cyclone Dust	5.6 E3 μg/g	2.2 E-2 g/s
Ash Pan Water	1.2 E4 μg/l	2.6 E-2 g/s

To provide a means of determining the general organic character of the discharge streams, the composite samples were analyzed using a column chromatography technique. Organic compounds were separated into seven fractions according to polarity. The organic loading of each fraction was then determined by TCO and GRAV analyses. The general organic character of the stream can be reviewed by relating the organic loading of each fraction to the organic compounds predicted to be in each fraction. Table C-2 in Appendix C identifies organic categories eluted in each of the seven fractions.

The solid residues of the GRAV analyses were analyzed for organic character by infrared spectroscopy (IR). IR can provide information about groups and bonding mechanisms of organic compounds on the basis of the absorption of light energy in the infrared region.

Table 4-20 presents general comments about discharge streams organic character indicated by LC and IR analyses. The information presented in this

TABLE 4-20. GENERAL COMMENTS ABOUT LC AND IR ANALYSES OF DISCHARGE STREAMS

Stream	Liquid Chromatography Comments	Infrared Spectroscopy Comments
Product Gas Aerosols	Order of dominance of L.C. fractions: 6-(1-4-5-3)*-7-2 - strong alcohol, phenol, ester, ketone, amine, alkyl sulfur compounds, amides, carboxylic acids and phosphates indicated - medium aliphatic hydrocarbons, ethers, epoxides, aldehydes, nitriles, heterocyclic sulfur and oxygen compounds and phosphates indicated - medium to weak halogenated hydrocarbons and aromatic and halogenated aromatic hydrocarbons indicated	- strong aromatic and aliphatic character - medium phenolic, amine and possibly heterocylic nitrogen and oxygen compounds character - medium to weak carboxylic acids, esters and ethers character
Product Gas Vapors	Order of dominance of L.C. fractions: 6-(1-5)-4-7-2-3 - strong alcohol, phenol, ester, ketone, amine, alkyl sulfur compounds, amides, carboxylic acids and phosphates - strong to medium aliphatic hydrocarbons and phosphates	- strong aromatic and aliphatic hydrocarbons, and carbonyl character - medium phenolic, esters, ethers, and carboxylic acids character
Gasifier Ash	Order of dominance of LC fractions: 1-2-6-3, 7-4-5 - strong aliphatic and halogenated aliphatic tendency - medium to weak aromatic and halogenated aromatic hydrocarbons and fused alternate, nonalternate hydrocarbons tendency	- strong aliphatic character - medium to weak aromatics, esters and ketones character

(Continued)

TABLE 4-20. Continued

Stream	Liquid Chromatography Comments	Infrared Spectroscopy Comments
Cyclone Dust	Order of dominance of LC fractions: 6-3-(4-1-5)-7-2 - strong alcohol, phenol, ester, ketone, amine, alkyl sulfur compounds, amides, carboxylic acids and phosphate tendency - medium to weak aromatic and halogenated aromatic hydrocarbons, and fused alternate, nonalternate hydrocarbons tendency	- predominantly aliphatic character - strong carbonyl character - medium to weak phenolic and amines character
Ash Pan Water	Order of dominance of LC fractions: 6-1-7-5-4-3-2 - strong alcohol, phenol, ester, ketone, amine, alkyl sulfur compounds, amides, phosphate and very strong carboxylic acids tendency - medium aliphatic hydrocarbons tendency - medium to weak halogenated aliphatic hydrocarbons tendency	- strong carbonyl and aliphatic character - medium to weak phenols and alcohols character

*Numbers in ( ) are similar in magnitude.

table is a summation of the major findings of the analyses and is not a complete presentation of the LC and IR analytical results. Generally, the LC and IR results support each other, except that the aromatic character of both product gas fractions shown by IR is not supported by LC. However, variations in LC and IR results may be due to LC analysis being performed on the whole sample, while IR analysis is performed on only the GRAV portion.

The five discharge stream extractable organic samples were analyzed for halogens (Cl, Br, I, F), and sulfur- and nitrogen-containing organic compounds using a gas chromatograph with a Hall electrolytic conductivity detector (GC/HECD). The technique quantifies the three compound classes individually and provides specific compound classifications as correlated to LC fractionation analyses. Table 4-21 presents the GC/HECD analytical results of the five effluent streams. Of significant interest are the halogen analyses, which provide an upper limit of the concentration of polychlorinated biphenyls. GC/MS identified the sulfur-containing compounds quantified by GC/HECD as elemental sulfur.

Specific organic compounds were identified and quantified using GC/MS. The non-fractionated samples were analyzed for priority pollutant organic compounds. Major peaks of the GC scan not identified and quantified as priority pollutants were quantified and qualitatively identified as large hydrocarbon compounds. These peaks were summed and presented as non-priority pollutant compounds in Table 4-22 which presents the GC/MS analytical results. Also presented in this table is the percentage of extractable organics of each stream quantified by GC/MS; the results show that a minor percentage of the extractable organics were quantified by GC/MS.

TABLE 4-21. GC/HECD ANALYTICAL RESULTS* FOR HALOGEN-, SULFUR- AND NITROGEN-CONTAINING ORGANIC COMPOUNDS

Stream	Halogen	Sulfur	Nitrogen
Product Gas Aerosols	<0.05 μg/g 16 μg/Nm^3	590 μg/g (2,200 μg/Nm^3)	327 μg/g (1,220 μg/Nm^3)
Product Gas Vapors	1,960 μg/Nm^3+	19,100 μg/Nm^3	26,500 μg/Nm^3
Gasifier Ash	0.43 μg/g	33.1 μg/g**	0.46 μg/g
Cyclone Dust	0.05 μg/g	24.5 μg/g	5.1 μg/g
Ash Pan Water	0.45 μg/1	11.1 μg/1	2.3 μg/1

* All single compound worst cases were reported as hydrocarbons. The assumption was made that moles of halogen = moles of n-alcane hydrocarbon. Then the amount of hydrocarbon was calculated in μg/Nm^3.

**Elemental sulfur present - 31.1 μg/g as analyzed by GC/MS.

+ Nm$_3$ = normal cubic meter (25°C, 1 atm).

TABLE 4-22. GC/MS ANALYTICAL RESULTS

Compound(s)	Product Gas Aerosols µg/g	µg/Nm^3	Product Gas Vapors µg/Nm^3	Gasifier Ash µg/g	Cyclone Dust µg/g	Ash Pan Water µg/g
Acenaphthene					0.8	
Acenaphthylene			24,800			2.0
Benzo(a)pyrene	1,450	5,400			1.5	
Bis(2-ethyl hexyl)phthalate	172	640	5,640	3.47		11.1
Chrysene/Benz(a)anthracene	1,270	4,730		0.25	2.2	2.4
Diethyl phthalate	137	510	1,710	0.14	0.7	1.9
Di-n-butyl phthalate			1,200	0.11		1.4
2,4-Dimethylphenol			3,160			
Fluoranthene	426	1,590	2,820	0.12	0.8	1.7
Fluorene			11,100			1.0
Naphthalene			41,900	0.13	1.5	7.4
Phenanthrene/Anthracene	389	1,450	15,400	0.06	0.9	2.2
Phenol					11.2	241.
Pyrene	544	2,030	2,900	0.12	0.7	1.7
Non-priority Pollutants	10,900	40,800	193,000	0.45	41.5	75.9
Solvent Extractable Organics Quantified*	1.73%		5.24%	2.02%	1.10%	2.91%

*Percentage of extractable organics of each stream quantified by GC/MS.

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APPENDIX A
PROCESS OPERATIONS

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A.1.0 INTRODUCTION

In December of 1979 the Riley Stoker Corporation conducted a test of its full-scale Riley Gas Producer fueled by North Dakota lignite. The test was held at Worcester, Massachusetts, and was jointly sponsored by American Natural Service Company (ANSC) and Riley Stoker Corporation. Radian Corporation participated in the test as part of its federally sponsored program to define and evaluate the environmental effects of low-Btu gasification technologies with respect to their multimedia discharge streams.

The ANSC test plan called for a three-day start-up period to gradually reach the peak lignite rate, estimated at 1500 g/s (12,000 lb/hr), followed by five days of steady state operation in which Radian would conduct its process data collection and sampling program. However, a series of problems occurred (mostly external to the gasifier) which forced Radian to sample over a one-day period and also prevented an accurate evaluation of the gasifier's capacity at this feed rate. A brief summary of the events during the twelve days between the initial light-off and the final shutdown follows.

The initial light-off was at 1050 hours on Tuesday, December 4. The gasifier ran smoothly. Later that same day, the combustion burner (a large test burner which combusted the entire low-Btu gas stream) experienced flame oscillation, vibrations, and loss of pilot flame. The burner safety interlock system prevented relighting the pilot while there was flame in the main burner. A large ring burner fueled by natural gas surrounded the single low-Btu gas burner. This ignitor ring flame enveloped the low-Btu gas flame and provided stability at low producer gas rates and protection against low-Btu gas flame-out. The decision was made, however, to shut down the entire system so that the burner interlock system could be revised to ensure the capability of pilot operation at all times. The gasifier came down at 1900 hours on December 4. The burner interlock system was reworked. Later it was determined that the vibration problems were due to excess primary air in the burner.

In an effort to save time, an attempt was made to relight the gasifier bed rather than removing it and replacing it with the synthetic startup ash, charcoal, or wood, used during a standard start-up. The risk was that during shutdown the ash bed could have been damaged by thermal shocks, high steam rates or other conditions. Relight was at 1700 hours on December 5. By the next morning, it was apparent that the relight had failed: there was extensive clinkering and areas of fire on the top of the bed. At this point, the decision was made to delay shutdown until late the next day, Friday, December 7. The gasifier was shut down at 1700 hours on Friday, December 7. During the shutdown period, modifications were also made to the feeder.

The third and final run began with a light-off at 1100 hours on Tuesday, December 11. Saturday, December 15, was set as the last possible shutdown date. The majority of Radian's sampling was conducted from midday on December 13 to midday on December 14. Around 1100 hours on December 14, the coal feed rate was increased sharply from 1050 g/s (8300 lb/hr) to 1350 g/s (10700 lb/hr). High bed pressure drop soon forced a rate cut. A rate of 900 g/s

(7200 lb/hr) was maintained during the balance of the test. Shutdown was at 0500 hours on December 15.

Although bed pressure drop appeared to limit the coal feed rate to 1050 g/s (8300 lb/hr), there was not enough time available at the end of the test to properly evaluate the gasifier's limitations on lignite operation.

A.2.0 SUMMARY

Radian's objective during the test was to collect process data and gather samples for on-site and off-site analyses for an environmental assessment of the Riley Gas Producer operating on lignite.

The material balance developed in this appendix will be used as the basis for trace element balances, weighted discharge severity calculations and other environmental assessment calculations which require stream mass flow rates. The component material and heat balances provide additional information about the gasifier's operation during the test.

A.3.0 PROCESS DESCRIPTION

The Riley Gas Producer is an adaptation of the Morgan Gas Producer. The gasifier used in the test is shown schematically in Figure A-1. The facility also includes coal handling equipment, ash removal equipment, a product gas cyclone and Riley's on-line sampling system and instrumentation. The hot producer gas is combusted in a separate burner for evaluation of flame characteristics. Except for a cyclone on the hot product gas, no gas purification processes were used. Wastewater from ash handling, cooling, and seal water flows was not treated but discharged directly to a sewer.

A.3.1 Coal Handling

Sized North Dakota lignite (screened at the mine) is delivered by truck to a series of enclosed conveyors which transport it to the 54 Mg (60 ton) coal bin. The bin is normally blocked in and slightly pressurized to 1250-2500 Pa (5-10 inches of water) with nitrogen. The lignite is gravity fed on demand to the feeder lock hopper and then to the continuous feeder. Two valves above the lockhopper and one below operate in sequence. A steam eductor draws a partial vacuum on the feeder lockhopper during part of the sequence. This combined with the pressurization of the coal bin effectively eliminates fugitive emission problems in the coal feed system.

The feeder is a horizontal slotted cylinder which drops coal through adjustable guide vanes and onto the surface of the rotating bed. Feed rate changes are made by varying feeder rotation rate. Regulation of gate openings within the feeder allows additional alteration of the coal feed distribution.

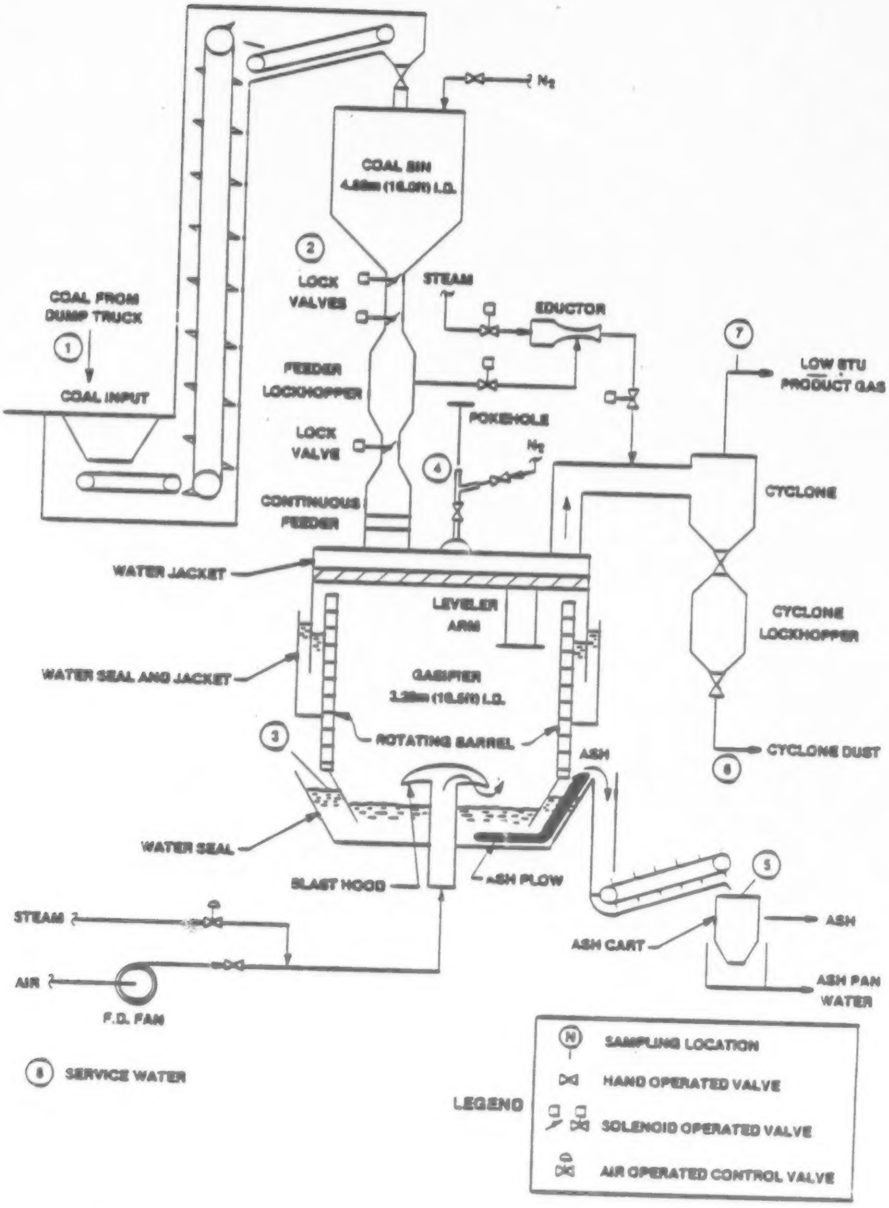
N₂
COAL BIN
4.88m (16.0ft) I.D.
②
LOCK VALVES
STEAM
EDUCTOR
COAL FROM DUMP TRUCK
①
COAL INPUT
⑦
LOW BTU PRODUCT GAS
FEEDER LOCKHOPPER
POKEHOLE
LOCK VALVE
N₂
④
CYCLONE
CONTINUOUS FEEDER
WATER JACKET
LEVELER ARM
CYCLONE LOCKHOPPER
WATER SEAL AND JACKET
GASIFIER
3.20m (10.5ft) I.D.
③
ROTATING BARREL
ASH
CYCLONE DUST
⑥
WATER SEAL
BLAST HOOD
ASH PLOW
⑤
STEAM
ASH CART
ASH
AIR
ASH PAN WATER
F.D. FAN
⑧ SERVICE WATER
LEGEND
Ⓝ SAMPLING LOCATION
HAND OPERATED VALVE
SOLENOID OPERATED VALVE
AIR OPERATED CONTROL VALVE

Figure A-1. Schematic of the Riley Gas Producer

A.3.2 Gasifier

The gasifier is an atmospheric pressure, thin-bed design in which the entire fixed bed rotates slowly, six and one half minutes per revolution. At the bottom of the bed, the ash zone holds about one day's production of ash. The active zone is directly above the top of the ash zone. In the Riley Gas Producer, an active zone thickness of about 45 cm (18 inches) is considered optimum. The highly exothermic portion of the active zone, the oxidation or fire zone, normally is about 10 cm (4 inches) thick.

When operating on anthracite or bituminous coals, the gasifier employs water-cooled leveler arms which ride just below the surface and agitate the top of the bed. These arms also indicate bed level. Lignite fractures too easily for constant agitation so these arms were not used during the test.

The gasifier's pokeholes (located on the stationary top) are equipped with nitrogen purges which effectively eliminate fugitive emissions during normal operations. The pokehole assemblies swivel over most of the bed to allow poking, visual observation of the surface of the bed, bed surface height determination, and fire zone height measurements.

Air to the gasifier is pressurized in a forced draft fan to approximately 7.5 kPa (30 inches of water). Saturated steam (164°C) is injected into the air stream to heat the air to the desired mixture temperature—the blast saturation temperature (BST). BST is a key process variable and is closely monitored. Too high a BST may produce small ash particles with resultant excessive bed pressure drops. Too low a BST results in a clinker formation which disrupts flow distributions and can require shutdown. Some of the steam condenses in heating the air and is discharged as condensate. The air/steam mixture enters the gasifier under the blast hood at the base of the ash zone.

Water seals at the bottom and top of the rotating side walls prevent the escape of product gas. The gasifier walls are internally lined with brick, and the water-cooled top is internally insulated with refractory. Parallel water flows are used for the seals, feeder cooling, top cooling, and leveler arm cooling. These flows are combined at the base of the gasifier and then discharged.

A.3.3 Ash Removal

The ash plow at the base of the gasifier normally rotates with the bed. Ash removal is accomplished by stopping the ash plow for one or two revolutions of the bed. The ash is pushed out by being forced against the then stationary helical spiral arm of the plow and then up along an inclined chute through the water seal and out of the gasifier. The frequency of ash removal depends on the coal feed rate, the ash content of the coal, the carbon content of the ash and the ash density.

Ash and a small amount of water are conveyed to a cart for ash disposal. The water passes through holes in the bottom of the cart, into a pan, and to the sewer. The ash in the cart is weighed and its volume determined. These measurements proved to be unreliable during the test period. The measured ash weights were 50 to 75 percent of the minimum amount of ash that would be produced based on the lignite analyses.

A.3.4 Low-Btu Product Gas

The low-Btu product gas exits the gasifier in a 91-cm (36-inch) inner diameter refractory-lined pipe and flows to an external cyclone. Most of the entrained particulate matter in the gas is recovered in the cyclone lock hopper. The cyclone exit gas line transports the product gas to a burner located approximately 50 meters from the gasifier. The transport line, which has a 74-cm (29 1/4-inch) inner diameter, is externally insulated and heat traced. The Riley on-line instrumentation sample location was just downstream of the cyclone. Radian's product gas sampling points were in the transport line between the cyclone and the burner, just downstream of Riley's sampling location.

A.3.5 Riley's On-Line Sampling and Instrumentation

Riley's on-line product gas sampling system consists of a heated sample station enclosing two parallel trains. Each train includes a 2.54-cm (1-inch) sample probe, a water-cooled condenser, a Balston Filter (Type D, 2 in by 9 in) and a diaphragm pump. The sample probes and condensers can be steam purged. The two trains join after the pumps (only one pump runs at a time), and a single line runs to the control room where a water-cooled condenser and a Balston Filter (Type D, 1 in by 7 in) remove any remaining condensate, particulates, tars and oils.

The purified gas flows to the following continuous analyzers: an MSA Analysis System (CO, CO_2, CH_4, and H_2), a Ranarex Specific Gravity Recorder, a Sigma Calorimeter, and a Teledyne O_2 Analyzer. Riley's instrumentation also measured temperatures, pressures and flows throughout the system. The product gas flow rate was not measured since tar fouling on previous runs prevented reliable measurements.

Bed temperatures inside the gasifier were not measured since no effective method has been developed for a rotating bed.

A.3.6 Utilities

While the utility requirements of a commercial unit would be different from those of the test facility, the test unit utilities are estimated here for completeness.

Electrical—

Air blower	9.5 J/g of lignite (2.4 kWh/ton)
Bed rotation, normal	2.3 J/g of lignite (0.58 kWh/ton)
Bed rotation, for plowing	0.2 J/g of lignite (0.05 kWh/ton)
Coal loading	0.5 J/g of lignite (0.13 kWh/ton)
Ash handling	0.1 J/g of lignite (0.03 kWh/ton)

(Electrical requirements vary with different feedstocks.)

Cooling Water— 2.2 l/s (35 gpm) with a temperature rise of 14°C (25°F) which equals about 120 J/g of lignite (50 Btu/lb); cooling water requirements vary with different feedstocks.

Nitrogen— 0.018 wt N_2/wt of lignite

The nitrogen consumption rate was measured during the 24-hour sampling period. Nitrogen was used to pressurize the coal bin and to purge the pokehole assemblies. Nitrogen consumption in a commercial unit should be much less since no attempt was made to conserve nitrogen during the test. Numerous bed checks and observations which were made during the test would not be necessary in a commercial unit. Steam is a possible lower cost substitute for pokehole purging gas.

A.4.0 GASIFIER OPERATION DURING RADIAN'S SAMPLING PERIOD

The average lignite feed rate was 1000 g/s (7900 lb/hr) during Radian's sampling period—1000 hours on December 13 to 1000 hours on December 14. The actual sampling efforts overlapped this approximate 24-hour period in several instances.

A.4.1 Process Variables

Important measured and calculated process variables are presented in Table A-1. These variables are presented in graphical form in Figures A-2, A-3, and A-4. The dry gas properties were calculated from Radian process gas chromatograph readings. The dry gas flow rate was obtained by nitrogen balance with the incoming air (after the air rate was adjusted as described in Section A.5.2.8). As Figure A-2 shows, the dry product gas flow rate increased steadily over the sampling period.

TABLE A-1. PROCESS VARIABLES

Date	Time Hrs	Dry Product Gas: Calc. Flow Rate	Dry Product Gas: Calc. Lower Heating Value**	Dry Product Gas: Calc. Molecular Weight	Blast Saturation Temp °C	Gasifier Exit Temp °C	Air Rate g/s	Air-to-Steam Ratio wt/wt	Bed Pressure Drop Pa
12/13	1000	NA	NA	NA	62.2	266	1365	5.98	2764
	1100	NA	NA	NA	62.8	273	1411	5.78	2689
	1200	NA	NA	NA	62.8	323	1429	5.78	2639
	1300	NA	NA	NA	62.8	386	1429	5.76	2689
	1400	1.92	5.22	24.87	62.8	360	1365	5.75	2615
	1500	1.95	4.75	25.12	61.7	339	1432	6.10	2166
	1600	1.96	5.13	24.88	61.7	267	1411	6.11	2266
	1700	2.10	5.25	24.80	63.3	253	1459	5.54	2166
	1800	2.06	5.32	24.75	63.3	272	1459	5.54	2241
	1900	2.08	5.17	24.77	62.3	343	1465	5.88	1892
	2000	2.03	4.95	25.08	63.3	338	1465	5.33	2042
	2100	2.04	4.91	25.06	63.9	315	1468	5.35	2017
	2200	2.11	5.37	24.78	63.9	299	1470	5.32	2017
	2300	2.13	5.33	24.79	63.3	229	1470	5.50	2017
	2400	2.20	5.48	24.83	63.9	230	1513	5.30	1718
12/14	0100	2.20	5.30	25.04	63.3	256	1554	5.50	1942
	0200	2.25	5.41	24.68	63.3	254	1557	5.50	1917
	0300	2.30	5.63	24.22	62.8	243	1554	5.68	1843
	0400	2.30	5.63	24.46	62.8	270	1554	5.67	1793
	0500	2.30	5.46	24.54	63.3	251	1551	5.49	1793
	0600	2.25	5.19	24.53	63.3	245	1554	5.49	1643
	0700	2.36	5.59	23.82	63.3	187	1551	5.48	1643
	0800	2.37	5.66	24.06	63.3	158	1557	5.50	1668
	0900	2.24	5.46	24.39	63.3	178	1559	5.54	1643
	1000	2.30	5.15	25.01	62.8	263	1557	5.30	1768

Notes: 1. Dry gas properties calculated from compositions measured by Radian process gas chromatographs (see Tables A-7 and A-8).
2. Dry gas flow rate estimated by nitrogen balance with measured air rate (after material balance adjustment to air rate).
3. Blast saturation temperature, gasifier exit temperature, air rate, steam rate and bed pressure drop are measured variables.
4. The air-to-steam ratio is calculated assuming the air is saturated at the blast saturation temperature.

*m³ at 25°C/s
**MJ/m³ at 25°C

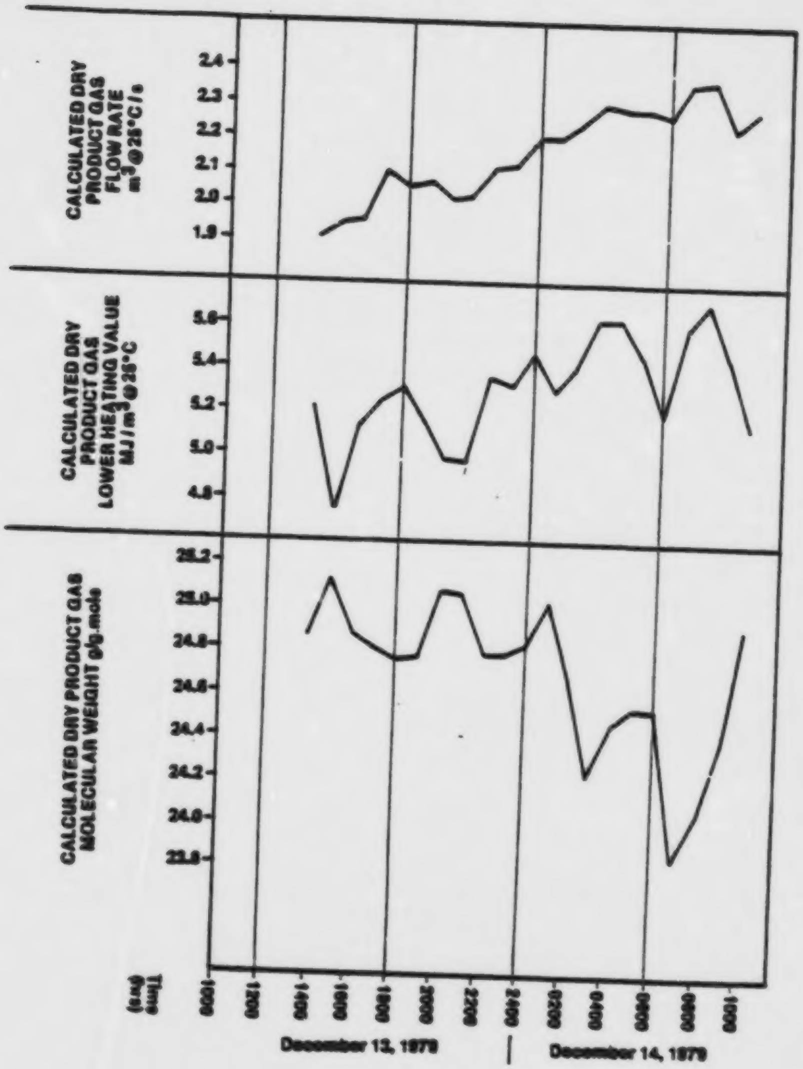

Figure A-2. Dry Gas Flow Rate, LHV and Molecular Weight Plots

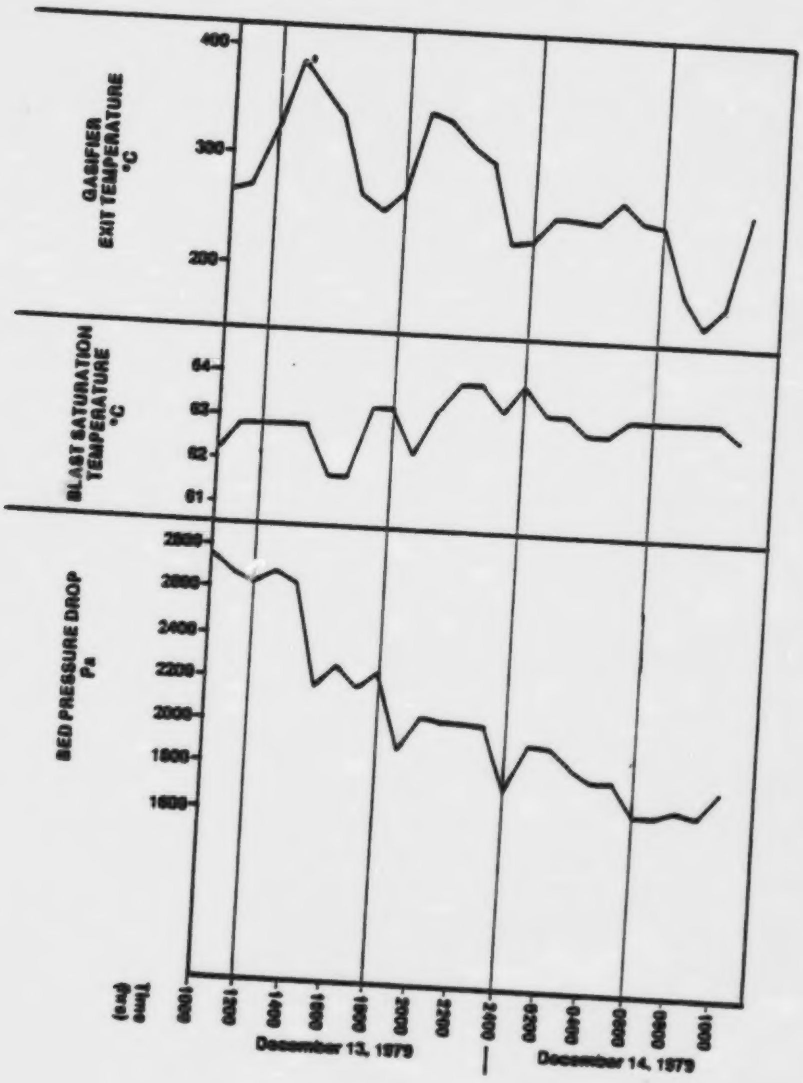

Figure A-3. Gasifier Exit Temperature, Blast Saturation Temperature and Bed Pressure Drop Plots

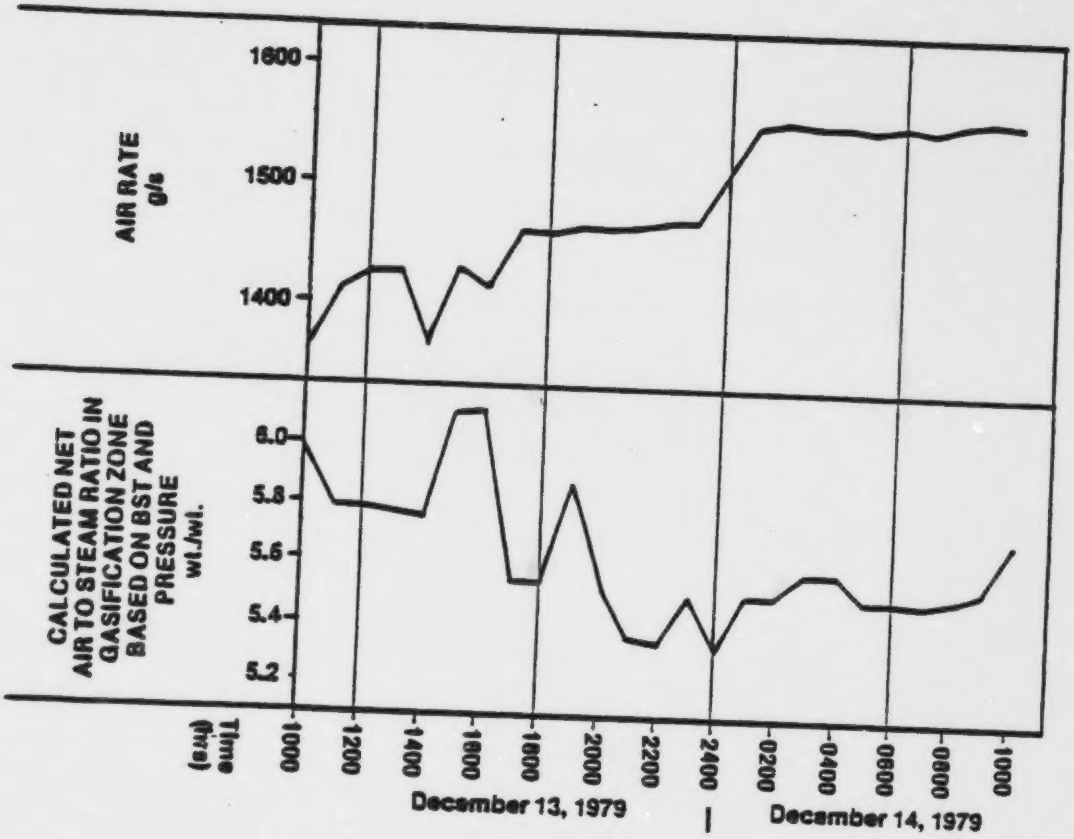

Figure A-4. Air Rate and Air-to-Steam Ratio Plots

As Figure A-3 shows, the gasifier exit temperature was not stable over most of December 13 and beyond 0600 hours on December 14. These and other fluctuations are to some extent the result of having manual controllers on the air, steam and coal flows. During periods of feed rate changes, manually balancing all the various flows is often difficult. Ratio controllers or a feedback control system would probably be included in any commercial unit. During the period of most stable operation (the period before 0600 hours on December 14), the feed rate remained fairly constant.

The bed pressure drop (Figure A-3) declined steadily over the sample period while the lignite, air and steam rates were increasing. A sharp increase in feed rate had been made at 0900 hours on December 13, just before the sample period. The bed pressure drop more than doubled between 0800 hours on December 13, then (as noted earlier) began to decline throughout the sample period.

Figure A-4 presents the adjusted air rates during the sampling period (see Section A.5.2.8 for adjustment). This figure also gives air-to-steam ratios. The air-to-steam ratio was fairly unstable until around 2000 hours on December 13.

A.4.2 Ambient Conditions

Table A-2 presents the ambient conditions during the sampling period. It snowed on December 13 and intermittently throughout the sampling period.

A.5.0 HEAT AND MATERIAL BALANCES

Heat and material balances have been constructed for 0400 hours on December 14. This particular time was selected because it is near the middle of a period when the feed rate was fairly constant, the feed rate was the highest stable rate observed during the test, and the process variables indicate nearly steady state. Heat and material balance calculations are somewhat complicated by the day or so delay between the time coal is sampled as it is loaded into the coal bin and the time that particular coal is gasified. In addition, ash made in the gasifier has a day or so residence time in the bottom of the gasifier before it can be sampled.

A.5.1 Stream Compositions and Properties

A.5.1.1 Coal

Analyses of various lignite samples indicate some variability, particularly in the sulfur and ash contents. The sulfur content of lignite delivered before 1200 hours on December 13 was significantly higher than later deliveries. Variability of ash analyses showed no pattern. The ranges of lignite analyses for December 13 and 14 are shown below.

TABLE A-2. AMBIENT CONDITIONS

Date	Time Hrs.	Ambient Temp. °C	Dew Point °C	Moisture in Air Wt. water/wt. dry air	Barometric Pressure kPa
Dec. 13	1000	1	-15	.0012	101.3
	1100	1			
	1200	1			
	1300	1	-14	.0012	101.0
	1400	0			
	1500	0			
	1600	0	-13	.0014	100.9
	1700	0			
	1800	-1			
	1900	-2	-16	.0011	100.7
	2000	-3			
	2100	-3			
	2200	-3			100.5
	2300	-3	-16	.0011	
	2400	-3			
Dec. 14	0100	-3			100.5
	0200	-3			100.5
	0300	-3	-16	.0011	
	0400	-2			
	0500	-2			100.6
	0600	-2	-17	.0010	
	0700	-3			
	0800	-2	-16	.0011	100.9
	0900	-2			
	1000	-2			

Component	Ranges of Lignite Analyses Wt. % dry basis
C	62.0 - 66.5
H	4.0 - 4.7
N	0.91 - 1.06
S	0.48 - 3.10
Ash	8.0 - 14.8
O	15.8 - 19.3
HHV	24,200 - 25,900 J/g

The lignite analysis used in the material balance for 0400 hours on December 14 is shown in Table A-3. This analysis was selected because of its time of delivery and because its ash and sulfur contents correspond with other data for 0400 hours on December 14.

A.5.1.2 Ash

The ash analysis used in the material balance is shown in Table A-4. This analysis was selected because it is of ash plowed almost a day after 0400 hours on the 14th and because its carbon content (27%) is reasonable for the gasification conditions observed.

A.5.1.3 Cyclone Dust

Table A-5 gives the cyclone dust analysis used in the material balance.

A.5.1.4 Tars and Oils

Table A-6 gives the tars and oils analysis used in the material balance. The tars and oils concentration in the product gas was determined from the material collected by an electrostatic precipitator followed by a condenser during Radian's sampling effort.

A.5.1.5 Dry Product Gas

Table A-7 lists the major gas components as recorded by Radian process chromatographs during the sampling period. Figure A-5 gives plots of these components. Table A-8 lists the minor gas components. The major and minor gas component concentrations are derived from the sequential readings of three separate chromatographs. Analyses from each chromatograph taken close to the indicated hour were combined with an assumed argon concentration of 5400 ppmv and normalized to 100 percent.

A.5.2 Overall Material Balance

An overall material balance for 0400 hours on December 14 based on the stream properties given in Section A.5.1 is presented in Table A-9. Figure

TABLE A-3. COAL ANALYSIS

Sample No. 77, taken from lignite being unloaded at 1415 hours on December 13.

	At Lab* Wt. %	At Gasifier* Wt. %
Moisture	5.57	34.1
C	59.93	41.82
H	4.06	2.83
N	1.00	0.70
S	0.45	0.31
Ash	10.80	7.54
O	18.19	12.70
	100.00	100.00
HHV, BTU/lb	9,983	6,967
HHV, J/g	23,220	16,205

*Radian tested coal moisture at the site. Samples lost moisture enroute to outside testing lab.

The net potential heat available in the lignite as delivered to the gasifier is given by its lower heating value (LHV). The LHV is calculated from the higher heating value (HHV) by deducting 2396 J for each gram of moisture (1030 Btu/lb) either originally in or produced by the combustion of one gram (lb) of lignite. This adjustment converts the liquid water products of the HHV test to the water vapor products which were actually produced.

$$\text{LHV} = 16205 - \left[2396(0.341 + (0.0283 \bullet \frac{18.02}{2.02}))\right] = 14{,}783 \text{ J/g}$$

TABLE A-4. ASH ANALYSIS

Sample No. 126, taken at 1415 hours on December 14, 1979.

	Lab Analysis Wt. %	Dry Basis Wt. %
Moisture	0.56	0
C	26.87	26.56
H	0.48	0.47
N	0.41	0.41
S	1.53	1.51
Ash	71.89	71.05
O	-	-
	101.74	100.00
HHV, BTU/lb	3,831	3,786
HHV, J/g	8,911	8,806

LHV is calculated by deducting 2396 J for each gram of moisture produced by the combustion of one gram of ash. This adjustment converts the liquid water products of the HHV test to vapor water products.

$$\text{LHV} = 8806 - \left[(0.0047)\ \frac{18.02}{2.02}\ (2396)\right] = 8706 \text{ J/g}$$

TABLE A-5. CYCLONE DUST ANALYSIS

Sample No. 153, composite sample from entire run.

	Lab Analysis Wt. %	Dry Basis Wt. %
Moisture	0.59	0
C	54.48	54.80
H	1.48	1.49
N	0.83	0.83
S	1.59	1.60
Ash	38.21	38.44
O	2.82	2.84
	100.00	100.00
HHV, BTU/lb	8,607	8,658
HHV, J/g	20,020	20,139

LHV is calculated by deducting 2396 J for each gram of moisture produced by the combustion of one gram of dust. This adjustment converts the liquid water products of the HHV test to vapor water products.

$$\text{LHV} = 20{,}139 - \left[(0.0149)\ \frac{18.02}{2.02}\ (2396)\right] = 19{,}821\ \text{J/g}$$

TABLE A-6. TARS AND OILS ANALYSIS

Composite sample from entire run.

	Dry Basis Wt. %
C	59.57
H	8.40
N	0.69
Cl	0.06
S	0.33
Ash	0.20
O	30.75
	100.00
HHV, BTU/lb	11,261
HHV, J/g	26,193

LHV is calculated by deducting 2396 J for each gram of moisture produced by the combustion of one gram of tars and oils. This adjustment converts the liquid water products of the HHV test to vapor water products.

$$\text{LHV} = 26{,}193 - \left[(.0840)\ \frac{18.02}{2.02}\ (2396)\right] = 24{,}398\ \text{J/g}$$

TABLE A-7. MAJOR GAS COMPONENTS

Date	Time Hrs.	Volume Percent on Dry Basis					
		CO	CO_2	H_2	O_2	N_2	CH_4
Dec. 13	1000	NA	NA	NA	NA	NA	NA
	1100	NA	NA	NA	NA	NA	NA
	1200	NA	NA	NA	NA	NA	NA
	1300	NA	NA	NA	NA	NA	NA
	1400	26.9	7.0	16.6	1.1	46.8	NA
	1500	24.1	8.6	16.6	1.1	48.2	0.6
	1600	26.1	7.2	16.5	1.0	47.3	1.0
	1700	28.0	6.8	16.7	1.2	45.8	0.7
	1800	27.1	6.6	16.7	1.1	46.5	1.2
	1900	27.4	6.7	16.9	1.2	46.4	0.7
	2000	24.6	8.3	16.5	1.1	47.6	1.0
	2100	25.3	8.0	16.5	1.1	47.5	0.7
	2200	27.3	7.1	16.8	1.0	45.7	1.2
	2300	27.4	7.2	16.9	1.0	45.6	1.1
	2400	27.6	7.1	16.6	1.1	45.3	1.4
Dec. 14	0100	26.6	7.7	16.0	0.9	46.6	1.4
	0200	27.0	7.1	17.1	1.0	45.6	1.3
	0300	27.7	6.4	18.0	1.1	44.5	1.5
	0400	28.2	6.2	17.4	1.2	44.8	1.5
	0500	28.9	6.3	17.3	1.2	44.7	0.9
	0600	25.7	7.7	18.3	1.3	45.4	0.9
	0700	28.8	6.3	18.7	1.3	43.3	0.9
	0800	29.2	5.9	19.0	1.1	43.2	NA
	0900	28.9	5.3	17.3	1.0	45.9	NA
	1000	26.4	8.9	17.2	1.2	44.8	NA

Notes: 1. Compositions are Radian process gas chromatograph readings normalized to 100 percent.

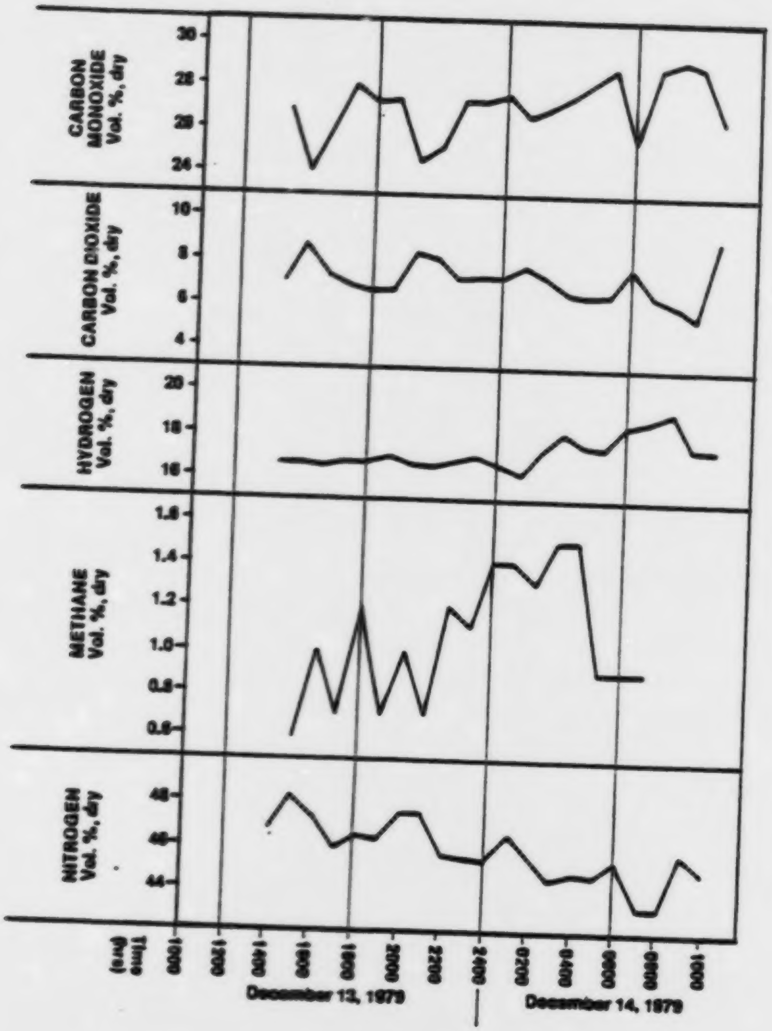

Figure A-5. Major Dry Gas Component Plots

TABLE A-8. MINOR GAS COMPONENTS

Date	Time Hrs.	C_2- (ethylene)	C_2 (ethane)	C_3 (propane)	C_4+ (butane and heavier)	COS	H_2S
Dec. 13	1000	NA	NA	NA	NA	NA	NA
	1100	NA	NA	NA	NA	NA	NA
	1200	NA	NA	NA	NA	NA	NA
	1300	NA	NA	NA	NA	NA	NA
	1400	190	441	160	261	NA	NA
	1500	211	321	201	261	135	1070
	1600	260	519	240	339	109	1238
	1700	213	364	202	263	121	1396
	1800	262	563	242	402	120	1418
	1900	214	295	173	265	168	1303
	2000	369	460	240	369	129	1178
	2100	260	339	199	260	129	1216
	2200	325	599	244	376	127	1320
	2300	265	499	204	346	117	1111
	2400	320	760	240	500	115	1130
Dec. 14	0100	344	636	290	484	145	1066
	0200	330	610	278	434	108	434
	0300	348	697	262	458	98	740
	0400	273	777	283	503	94	650
	0500	220	460	210	335	99	367
	0600	232	485	221	353	99	420
	0700	181	498	272	362	101	431
	0800	NA	NA	NA	NA	NA	NA
	0900	NA	NA	NA	NA	NA	NA
	1000	NA	NA	NA	NA	NA	NA

All values are in ppmv on dry basis.

Notes: 1. Compositions are Radian process gas chromatograph readings normalized to 100 percent.

2. Argon was not measured and is assumed to be 5400 ppm for all periods.

3. Gas property calculations assume the C_4+ portion to be 35 vol. % C_4, 17 vol. % C_5 and 48 vol. % C_6.

TABLE A-9. OVERALL MATERIAL BALANCE

For 0400 hours, December 14, 1979

	g/s	(lb/hr)	°C	(°F)
Inputs				
Coal	1,045	(8,292)	-2	(29)
Net Steam	274	(2,174)	164	(328)
Air	1,554	(12,334)	-2	(29)
Total	2,873	(22,800)		
Outputs				
Dry Gas	2,299	(18,245)	270	(518)
Moisture	440	(3,492)	270	(518)
Tars and Oils	21.5	(171)	270	(518)
Cyclone Dust	4.3	(34)	270	(518)
Ash	108	(858)	93	(200)
Total	2,873	(22,800)		

This balance has been adjusted so that inputs equal outputs. Explanation of this adjustment is given in Section A.5.2.8.

A-6 is a simplified process flow diagram illustrating this balance. The process conditions used are those that were recorded from the Riley instrumentation for 0400 hours on December 14. The goal in deriving this balance (and the heat balance which follows it) was to obtain a snapshot of the gasifier at a representative period. The methods used to construct the adjusted material balance given in Table A-10 are also presented.

A.5.2.1 Coal Feed Rate

The lignite gasification rate at 0400 hours was determined indirectly. Coal feeder measurements are not reliable indicators of the instantaneous gasification rate due to short term fluctuations in feeder delivery rate, gasifier inventory changes and the fact that the gasification rate is determined by the air rate. The average lignite rate for the 24-hour period was 997 g/s (7916 lb/hr) based on truck deliveries and coal bin inventory changes.

Since the gasification rate is proportional to the air rate, the ratio of the instantaneous air rate at 0400 hours to the average air rate for the 24-hour sampling period should be the same as the ratio of the instantaneous gasification rate to the average gasification rate. The ratio of the indicated air rate at 0400 hours to the average indicated air rate for the 24-hour sampling period is 1.048. Multiplying this factor by the average lignite feed rate of 997 g/s (7916 lb/hr) gives a gasification rate for 0400 hours of 1045 g/s (8292 lb/hr).

A.5.2.2 Air and Steam Rates

The air and steam flows were calculated from the Riley flow meter readings. The indicated air flow rate was 1312 g/s (10410 lb/hr) and the indicated steam rate was 295 g/s (2340 lb/hr). Since part of the steam condenses to heat the air, the net steam to the gasifier is determined by assuming that the air is saturated at the blast saturation temperature. At the process conditions at 0400 hours, the inlet air would hold 0.176 weight of steam per weight of dry air. Based on the indicated air rate, the net steam rate was 231 g/s (1835 lb/hr). The air and net steam flows were increased in the adjusted balance (see Section A.5.2.8).

A.5.2.3 Dry Gas Rate

Radian measured the product gas velocity and determined an average velocity of 13.0 m/s (42.6 ft/s) and a typical moisture content of 25.6 percent. These measurements plus the pipe dimensions and the exit gas temperature at 0400 hours produce a typical dry gas rate of 2.30 m^3/s (4718 scfm). At the measured (at 0400 hours) dry gas molecular weight of 24.46, this flow corresponds to a mass rate of 2299 g/s (18,245 lb/hr) for a gas temperature of 270°C (518°F).

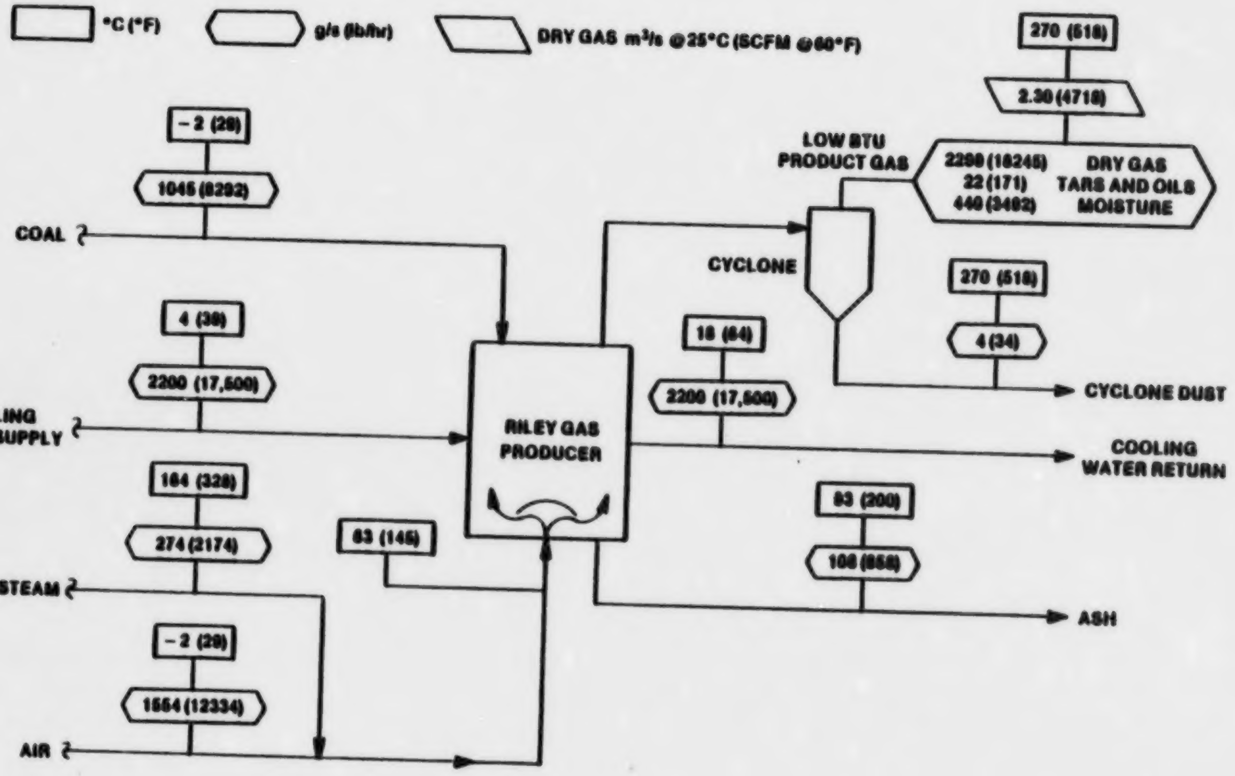
°C (°F)
g/s (lb/hr)
DRY GAS m³/s @25°C (SCFM @60°F)
COAL
−2 (28)
1045 (8292)
COOLING WATER SUPPLY
4 (39)
2200 (17,500)
STEAM
164 (328)
274 (2174)
AIR
−2 (29)
1554 (12334)
63 (145)
RILEY GAS PRODUCER
CYCLONE
LOW BTU PRODUCT GAS
270 (518)
2.30 (4718)
2298 (18245) DRY GAS
22 (171) TARS AND OILS
440 (3492) MOISTURE
270 (518)
4 (34)
CYCLONE DUST
18 (64)
2200 (17,500)
COOLING WATER RETURN
93 (200)
108 (858)
ASH

Figure A-6. Simplified Process Flow Diagram

TABLE A-10. COMPONENT MATERIAL BALANCES

	Total Flow			Ash			Carbon			Nitrogen			Oxygen			Hydrogen			Sulfur			Argon		
	g/s	(lb/hr)	Wt. %	g/s	(lb/hr)	Wt. %	g/s	(lb/hr)	Wt. %	g/s	(lb/hr)	Wt. %	g/s	(lb/hr)	Wt. %	g/s	(lb/hr)	Wt. %	g/s	(lb/hr)	Wt. %	g/s	(lb/hr)	Wt. %
Inputs																								
Coal	1045	(8292)	100.0	78	(622)	7.5	437	(3466)	41.8	7	(58)	0.7	451	(3574)	43.1	69	(547)	6.6	3	(25)	0.3			
Wet Stream	274	(2174)	100.0										243	(1931)	88.8	31	(243)	11.2						
Air	1554	(12334)	100.0					(1)	0.01	1173	(9305)	75.5	361	(2868)	23.2		(1)	0.01				20	(159)	1.3
Total In	2873	(22800)		78	(622)		437	(3467)		1180	(9363)		1055	(8373)		100	(791)		3	(25)		25	(159)	
Outputs																								
Product Gas																								
Dry Gas	2299	(18245)	100.0				412	(3266)	17.9	1179	(9360)	51.3	646	(5127)	28.1	39	(310)	1.7	2	(18)	0.1	21	(164)	0.9
Moisture	440	(3492)	100.0										391	(3101)	88.8	49	(391)	11.2						
Tars and Oils	22	(171)	100.0			0.2	13	(103)	59.6		(1)	0.7	7	(53)	30.8	2	(14)	8.4			0.3			
Cyclone Dust	4	(34)	100.0	2	(13)	38.5	2	(19)	54.9			0.8		(1)	2.8			1.5		(1)	1.6			
Ash	108	(858)	100.0	76	(610)	71.0	29	(228)	26.6		(3)	0.4				1	(4)	0.5	2	(13)	1.5			
Total Out	2873	(22800)		78	(623)		436	(3616)		1179	(9364)		1044	(8282)		91	(719)		4	(32)		21	(164)	
Out-In	0	(0)		0	(1)		19	(149)		-1	(1)		-11	(-91)		-9	(-72)		1	(7)		1	(5)	
Out\In In, wt. %			0			0			4			0			-1			-9			33			5

A.5.2.4 Moisture Rate

The typical moisture content of the product gas measured by Radian corresponds to a moisture flow of 0.80 m^3/s (1623 scfm). This rate is equivalent to a mass flow of 583 g/s (4624 lb/hr) at 270° (518°F). This flow was reduced in the adjusted material balance (see Section A.5.2.8).

A.5.2.5 Tars and Oils Rate

Radian measured a total loading of $9.09 \times 10^6 \mu g/Nm^3$ (4.09 grains/scf) of dry product gas. This loading times the dry product gas rate given in Section A.5.2.3 gives a tars and oils rate of 21.5 g/s (171 lb/hr).

A.5.2.6 Cyclone Dust Rate

A malfunctioning cyclone lockhopper prevented any dust recovery during the test. Riley later reported that 953 kg (2100 lb) of dust was collected in the cyclone during the entire test. A total of 232,000 kg (512,000 lb) of lignite was gasified over the total test period. The average dust rate is therefore 0.0041 weight of dust per weight of lignite.

For a lignite feed rate of 1045 g/s (8292 lb/hr), the dust rate is 4.3 g/s (34 lb/hr).

A.5.2.7 Ash Rate

The weights and volumes of ash recorded during the test do not agree with other data. The measured ash rates were 50-75 percent of the minimum amount that would have been produced based on lignite analyses.

The ash rate was determined by ash balance from the lignite rate, the cyclone dust rate and the ash contents of lignite, cyclone dust and ash. By this method, the ash rate at 0400 hours on December 14 was 108 g/s (858 lb/hr).

A.5.2.8 Material Balance Closure

The compositions and rates previously presented gave a raw material balance closure of plus 17 weight percent (total output mass flow minus total input mass flow, divided by total input mass flow). There are essentially three independent flows in the balance — lignite, air, and product gas. The lignite rate for 0400 hours is 105 percent of the average lignite rate for 24-hours, which is a well-defined stream based on commercial scale weights of the deliveries. Although the product gas rate determination method is subject to some errors, the most common errors (such as tar fouling or tube leaks) give lower readings, so the actual gas rate would be higher and that would increase the imbalance. While there is no specific evidence that the indicated air rate was in error, several factors suggest that was the case:

- The lignite and product gas rates substantiate each other with respect to carbon balance and volume of dry gas produced per unit weight of lignite (34.1 DSCF/lb versus a typical value of 35 DSCF/lb).

- A nitrogen balance between the incoming air (indicated) and the product gas shows about 18 percent more nitrogen leaving the system than entering.

- Though the air meter was zeroed and calibrated before and after the test, the air orifice was inaccessible and could not be checked.

As a result of these factors and in order to close the balance, the air rate for the adjusted balance was set by a nitrogen balance. The adjusted air rate is 18 percent greater than the indicated air rate. This same scale factor was also used to estimate the air rate at other time periods. The adjusted air rate for 0400 hours is 1554 g/s (12,334 lb/hr).

Since the net steam rate is a function of the air rate, the net steam rate also increases by 18 percent to 274 g/s (2174 lb/hr).

Increasing these two input rates improves the overall material balance closure to plus five percent. The component balances (ash, carbon, nitrogen, oxygen, hydrogen, sulfur and argon) at this point are all within 4 percent except oxygen and hydrogen, which are plus 11 and plus 7 percent, respectively.

This condition suggests that one of the moisture flows is incorrect. To achieve closure, the product gas moisture flow was decreased. This final adjustment is supported by two observations:

- The adjusted moisture content of the product gas of 20.6 volume percent is within the range of measured moistures.

- The calculated steam decomposition before the moisture adjustment is an unrealistically low 2 percent, while the calculated decomposition after the adjustment is a more realistic 70 percent.

The steam decomposition calculation determines what percent of the moisture entering the gasification zone reacts with the coal. The value of 70 percent may be slightly high since the calculation assumes that the only moisture entering the gasification zone is the net steam flow. In fact, some of the lignite moisture may enter the zone and/or some liquid moisture may be entrained in the inlet air. Either of these two conditions would reduce the actual steam decomposition percentage.

The overall component balances for the adjusted material balance are given in Table A-10.

A.5.3 Overall Heat Balance

A.5.3.1 Heat Balance Calculation

Table A-11 is an overall heat balance based on the adjusted overall material balance, the measured stream temperatures, and the stream compositions and properties given in Section A.5.1. Two types of heat flows are given in the balance, sensible and potential.

Sensible heat is defined as the amount of heat energy that is required to change the stream from the reference conditions of 25°C and liquid water to the actual stream temperature and water phase. Two of the streams, lignite and air, are cooler than 25°C so their sensible heat flows are negative. Potential heat in the balance is defined as the heat energy that would be generated if the stream were completely burned. To be consistent with the sensible heat reference conditions, higher heating values (HHV) are used to construct the balance. The dry product gas HHV was calculated from the measured gas composition using published gross heats of combustion for CO, H_2, CH_4, etc.

The raw heat balance was within one percent of closure (heat out minus heat in, divided by heat in). In the balance in Table A-12, this difference in total inputs versus total outputs is shown as "Unaccounted for Losses".

A.5.3.2 Gasifier Efficiencies

Gasifier efficiencies indicate the ability of the process to convert heat energy in the feed streams into heat energy in the product streams. The main goal is to compare the useful heat energy available in the feeds to the useful energy available in the products. While the higher heating values are required in the overall heat balance to be consistent with the enthalpy basis for efficiency calculations, lower heating values (LHV) are more representative of the available heat energies. In the HHV test, the heat required to vaporize liquid water in the fuel and to form water vapor from the hydrogen in the fuel ($H_2 + 1/2\ O_2 \rightarrow H_2O$) is recovered and included in the reported higher (or "gross") heating value. The fuel's LHV is calculated by subtracting the latent heat of the moisture in the combustion products from the HHV, and represents the heat energy which is actually available in the fuel. For this reason, the fuel's LHV values (as given in the tables in Section A.5.1) are used to calculate efficiencies. The dry product gas LHV was calculated from the measured gas composition using published net heats of combustions for CO, H_2, CH_4, etc. The calculated dry gas LHV of 156 Btu/scf corresponds well to the Riley on-line calorimeter value of 161 Btu/scf (both for 0400 hours on December 14, 1979).

Table A-12 gives the potential heat flows based on the lower heating values. Using these potential heat flows plus the sensible heat flows from

TABLE A-11. OVERALL HEAT AND MATERIAL BALANCE

	Mass Flow Rate		Temperature		Type of Heat*	Enthalpy*		Heat Flow Rate		Percent
	g/s	(lb/hr)	°C	(°F)		J/g	(Btu/lb)	kJ/s	(1000 Btu/hr)	
Inputs										
Coal	1,045	(8,292)	-2	(29)	Potential Sensible	16,205 -33	(6,967) (-14)	16,934 -34	(57,770) (-116)	96.0 -0.2
Wet Steam	274	(2,174)	164	(328)	Sensible	2,847	(1,224)	780	(2,661)	4.4
Air	1,554	(12,334)	-2	(29)	Sensible	-28	(-12)	-44	(-148)	-0.2
Total	2,873	(22,800)						17,636	(60,167)	100.0
Outputs										
Dry Gas	2,299	(18,245)	270	(518)	Potential Sensible	6,020 265	(2,588) (114)	13,840 609	(47,218) (2,080)	78.5 3.5
Moisture	440	(3,492)	270	(518)	Sensible	2,910	(1,251)	1,280	(4,368)	7.3
Tars and Oils	21.5	(171)	270	(518)	Potential Sensible	26,193 205	(11,261) (88)	563 4	(1,926) (15)	3.2 –
Cyclone Dust	4.3	(34)	270	(518)	Potential Sensible	20,139 205	(8,658) (88)	87 1	(294) (3)	0.5 –
Ash	108	(858)	93	(200)	Potential Sensible	8,806 58	(3,786) (25)	951 6	(3,248) (21)	5.4 –
Heat to Cooling Water								128	(437)	0.7
Unaccounted for Losses								167	(557)	0.9
TOTAL	2,873	(22,800)						17,636	(60,167)	100.0

*Enthalpy basis is 25°C (77°F) and H_2O liquid. Potential heats are based on the higher heating value (HHV).

TABLE A-12. POTENTIAL ENERGY FLOWS BY LOWER HEATING VALUE

	Mass Flow Rate g/s	LHV J/g	LHV Heat Flow Rate kJ/S
Lignite Feed	1,045	14,783	15,448
Dry Gas	2,299	5,636	12,957
Tars and Oils	21.5	24,398	525
Cyclone Dust	4.3	19,821	85
Ash	108	8,706	940

Table A-11, gasifier efficiencies were calculated and are presented in Table A-13. The base efficiency of the gasifier, which compares the potential heat of the product gas to the potential heat of the lignite, is 83.9%. For a typical hot gas installation, in which the product gas is combusted without cooling, the gasifier converts 87.9% of the useful input energy into product gas. For a system where the gas is cooled, the sensible heat of the gas is removed as are the tars and oils. The cold gas efficiency is 79.5%. If the tars and oils can be recovered and used as fuel, the cold gas efficiency improves to 82.8%. The actual efficiency of a cold gas installation would be slightly lower than these values depending on the energy consumption of the gas purification equipment required.

TABLE A-13. GASIFIER EFFICIENCIES

E_{Base} = Dry product gas potential heat/lignite potential heat

$$= \frac{12,957}{15,448} = 83.9\%$$

$E_{Hot\ Gas}$ = Useful energy in products/useful energy in feeds, for a hot gas system

= Potential plus sensible heat of dry product gas and tars and oils plus the sensible heat of the product gas moisture (excluding the latent heat of water vapor)/potential plus sensible heat of lignite and air, plus the heat required to produce the gross steam to the gasifier

$$= \frac{12,957 + 609 + 525 + 4 + 1280 - (2.396\ kJ/g)(440\ g/s)}{15448 + (-34) + (-44) + 921}$$

$$= \frac{14321}{16291}$$

$$= 87.9\%$$

$E_{Cold\ Gas}$ = Useful energy in products/useful energy in feeds, for a cold gas system

= Potential heat of dry product gas/potential plus sensible heat of lignite, air and gross steam

$$= \frac{12957}{15448 + (-34) + (-44) + 921}$$

$$= \frac{12957}{16291}$$

$$= 79.5$$

Note: Potential heat flows are based on lower heating values (see Table A-12). Sensible heat flows are relative to 25°C, liquid water (see Table A-11). The heat required to produce the gross steam to the gasifier is based on the total steam flow (rather than the calculated net steam flow) and an assumed boiler efficiency of 85% in producing that flow. (783 kJ/s 0.85 = 921 kJ/s)

APPENDIX B
SAMPLE COLLECTION TECHNIQUES AND FIELD SAMPLING DATA

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B.1.0 INTRODUCTION

This appendix describes the sampling locations and sampling techniques used during the environmental characterization of the Riley Gas Producer. Figure B-1 is a simplified schematic of the facility with the eight sampling locations, which are numbered as follows:

Gas Streams -

- Product Gas (7),
- In-Plant Fugitives (2), and
- Pokehole Gas (4).

Solid and Liquid Streams -

- Lignite (1),
- Gasifier Ash (5),
- Cyclone Dust (6),
- Ash Pan Water (3), and
- Service Water (8).

The following sections describe the types of samples collected at each location and the sampling techniques used. Section 6.0 is a complete log of all the samples collected.

B.2.0 PRODUCT GAS

The product gas exits the gasifier through the top section and is transported to a cyclone through a refractory-lined pipe. The cyclone is of stainless steel construction and externally insulated. The product gas is then transported to a combustor.

The sampling location for the product gas was approximately 25 meters downstream of the cyclone. Access to the product gas stream for the collection of samples was through a 10.2 centimeter (4-inch) gate valve mounted horizontally on the 0.76 meter (30-inch) product gas line. A 5.1 centimeter (2-inch) valve mounted at 90° with respect to the 10.2 centimeter valve was used in conjunction with the 10.2 centimeter valve in determining the velocity profile and total flow of the product gas at the sampling location. The product gas was characterized with respect to the following parameters:

- Ammonia,
- Cyanide,
- Trace Elements,
- Light, Medium, and Heavy Organic Vapor,
- C_1–C_6 Hydrocarbons,

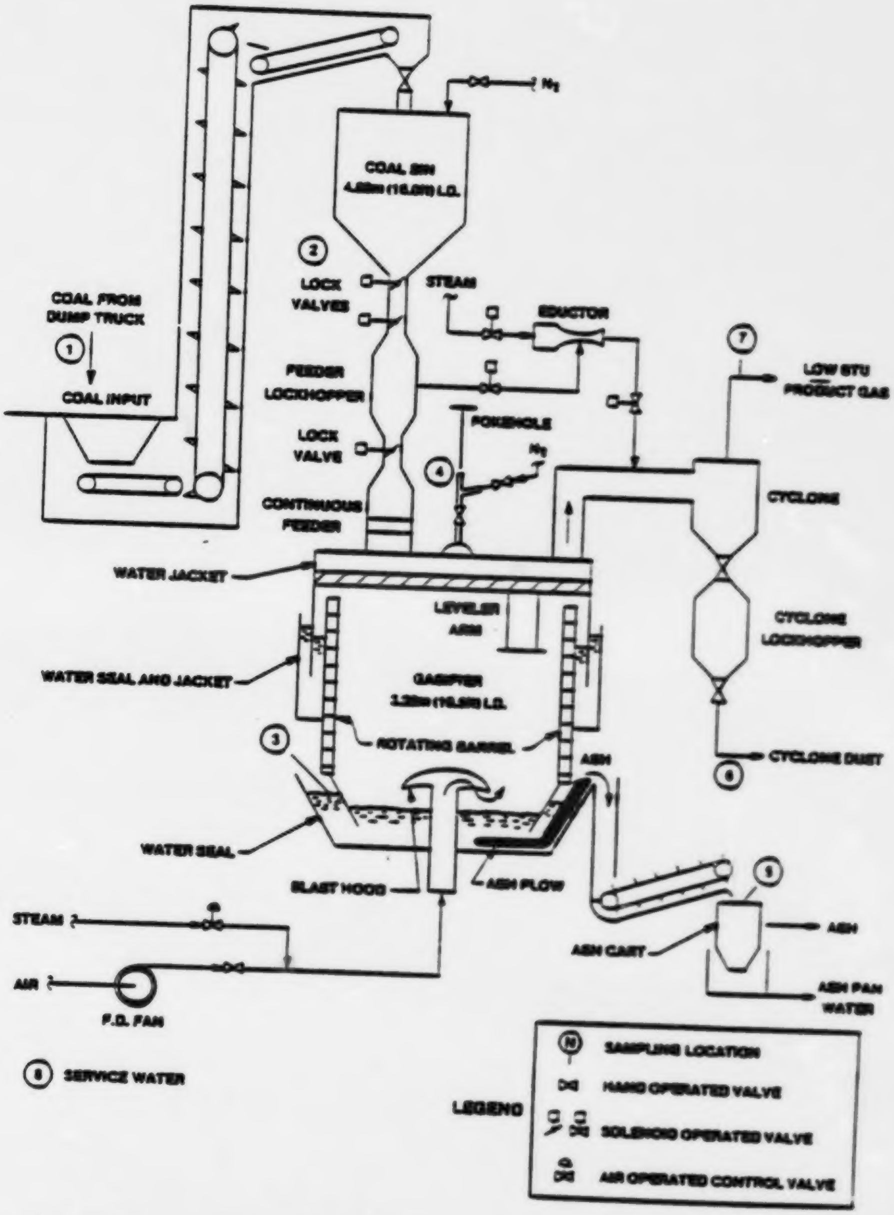

N2
COAL BIN
4.88m (16.0ft) I.D.
2
LOCK VALVES
STEAM
EDUCTOR
COAL FROM DUMP TRUCK
1
COAL INPUT
7
LOW BTU PRODUCT GAS
FEEDER LOCKHOPPER
POKEHOLE
LOCK VALVE
N2
4
CONTINUOUS FEEDER
CYCLONE
WATER JACKET
LEVELER ARM
CYCLONE LOCKHOPPER
WATER SEAL AND JACKET
GASIFIER
3.20m (10.5ft) I.D.
ROTATING BARREL
3
ASH
CYCLONE DUST
6
WATER SEAL
BLAST HOOD
ASH FLOW
5
STEAM
ASH
ASH CART
AIR
F.D. FAN
ASH PAN WATER
8 SERVICE WATER
LEGEND
N SAMPLING LOCATION
HAND OPERATED VALVE
SOLENOID OPERATED VALVE
AIR OPERATED CONTROL VALVE

Figure B-1. Schematic of Riley Gas Producer with Sampling Points

- Major Components,
- Trace Sulfur Gases,
- Particle Size Distribution, and
- Particulate Loading.

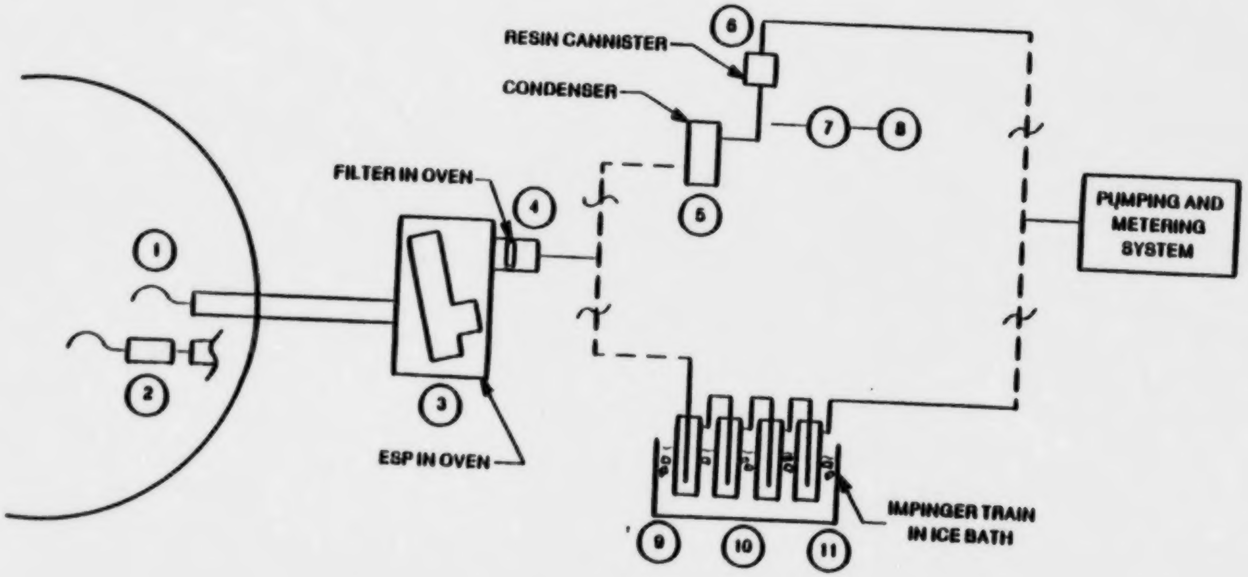
The basic system used for sampling (Figure B-2) consisted of:

- a stainless steel gooseneck nozzle of known inner diameter,
- an "S-type" pitot and thermocouple located near the nozzle tip,
- a stainless steel probe with a heated stainless steel sample line,
- a heated electrostatic precipitator (ESP),
- a heated glass fiber filter to serve as a backup for the ESP,
- a condenser and sorbent containers for organic sampling or an impinger train for inorganic sampling, and
- a dry gas meter to measure sample gas volumes and a leak-less diaphragm pump to draw the sample.

Measurements of velocity and temperature were made at the sampling point in order to maintain an isokinetic sampling rate. Because the product gas stream was laden with aerosol oils and tars, the use of a conventional filter to clean the gas stream would have been impractical due to rapid plugging of the filter substrate. Therefore, an electrostatic precipitator (Figure B-3) was used to remove particulates and aerosol oils and tars from the product gas before filtering.

The gas stream entered the lower portion of the ESP and was directed downward toward a collection cup at the bottom of the ESP; thus large aerosol material was removed by impaction prior to the electric potential collection zone of the ESP. As the gas stream moved upward through the ESP, electrostatic collection was induced by a 10-KVDC potential between the 0.25 mm center electrode and the cylindrical shell. Colloidal-size aerosols became ionized by the negative charge applied to the center wire electrode. As the particles migrated, they were forced to coalesce by their ultimate contact with the outer shell and other aerosol particles. Accumulated oils and tars flowed down the walls to the collection cup at the bottom of the ESP. The cleaned gas exited the ESP near its top. Most collection occurred near the base of the ESP; the upper portions remained relatively free of collected material.

ESP's of this configuration have been shown to be 95+% efficient for dry material of colloidial size. However, the primary reason for the use of the ESP was its ability to remove particulate and oil and tar aerosols without


RESIN CANNISTER
CONDENSER
FILTER IN OVEN
ESP IN OVEN
PUMPING AND METERING SYSTEM
IMPINGER TRAIN IN ICE BATH
①
②
③
④
⑤
⑥
⑦
⑧
⑨
⑩
⑪

① VELOCITY AND TEMPERATURE ("S-TYPE" PITOT AND THERMOCOUPLE)
② PARTICULATE SIZE DISTRIBUTION (CASCADE IMPACTOR)
③,④ PARTICULATE LOADING (ESP AND FILTER)
③,④,⑤ CONDENSABLE ORGANICS (ESP FILTER AND CONDENSER)
⑥ MEDIUM TO HEAVY ORGANICS (XAD-2 RESIN)
⑦ LIGHT ORGANIC VAPORS (LOW LEVEL, TENAX/SILICA GEL)
⑧ LIGHT ORGANIC VAPORS (HIGH LEVEL, CHARCOAL TUBE)
⑨ NH_3 (5% H_2SO_4)
⑩ HCN^-, SCN^- (10% NaOH)
⑪ TRACE ELEMENTS (5% HNO_3^-, 10% NaOH)

Figure B-2. Product Gas Sampling System

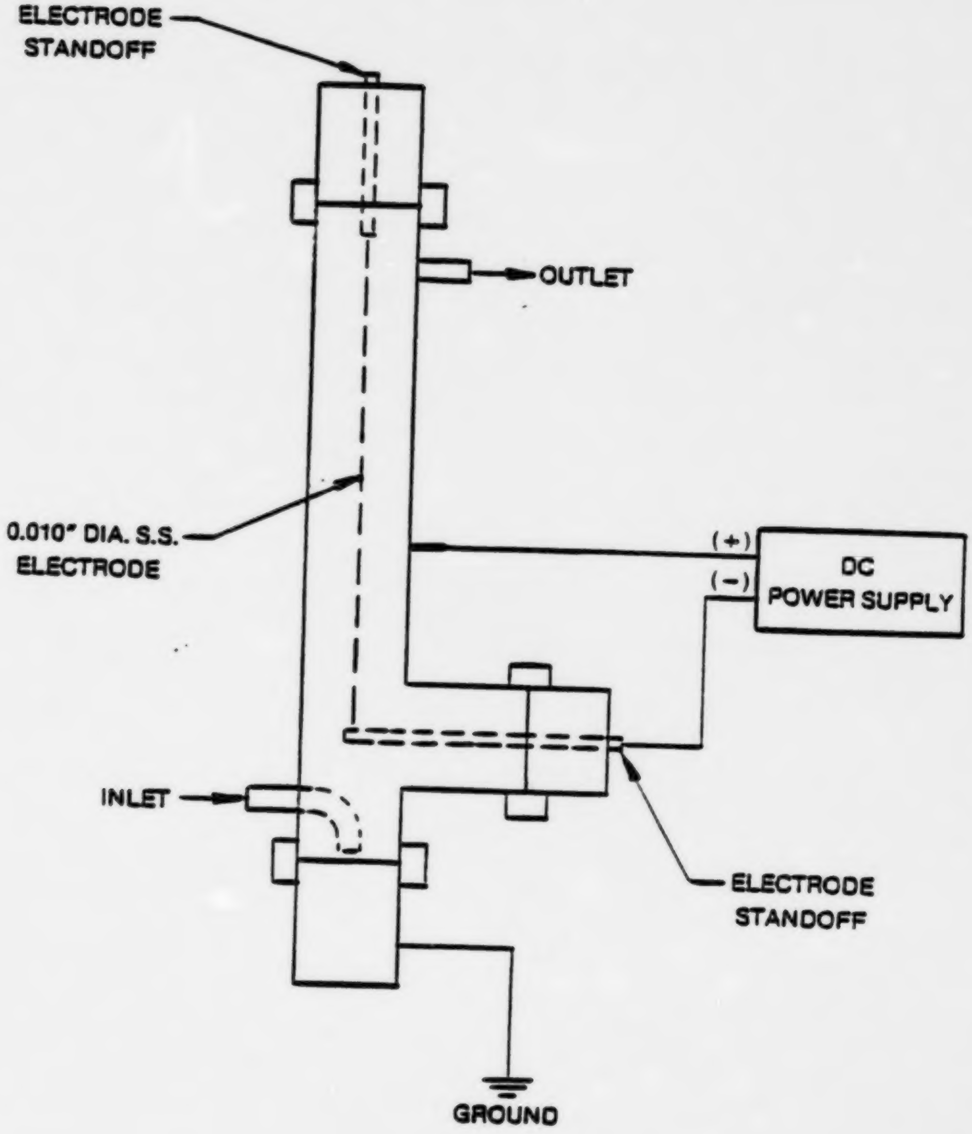

ELECTRODE STANDOFF
OUTLET
0.010" DIA. S.S. ELECTRODE
(+)
(−)
DC POWER SUPPLY
INLET
ELECTRODE STANDOFF
GROUND

Figure B-3. Schematic of ESP Used for Aerosol and Particulate Removal frequent servicing or changing out a filtering element. A glass fiber filter was used at the exit of the ESP as a polish and backup in the event of an ESP failure. A stainless steel ball valve was placed prior to the filter holder so that filter elements could be changed quickly and easily. The ESP and filter were maintained at 115°C (240°F). Figure B-4 shows the ESP and filter configuration.

After exiting the ESP, the gas stream was split so that two impinger trains could be run simultaneously. A stainless steel needle valve was used to control the gas sampling rate through each impinger train. The impinger sampling systems were operated at a slight negative pressure in order to avoid potential leaks that could result if the impingers were operated at a positive pressure.

Material collected by the nozzle, probe, ESP, and filter was kept separate through a portion of the analytical matrix. Table B-1 presents the method used to calculate the collection efficiency of the ESP, which was 98.0%.

Before gaseous and particulate samples were collected, a velocity traverse measurement of the product gas was performed. Twenty-four points were determined for the measurement of stream velocity and temperature using an "S-type" Pitot and a thermocouple. Twelve traverse points were on each of two diameters located 90° apart. Traverse points within one inch of the duct wall were not sampled.

TABLE B-1. COLLECTION EFFICIENCY OF SAMPLING ELECTROSTATIC PRECIPITATOR

Material Collected by ESP:	
Organic	16.98 grams
Inorganic	0.99 grams
	17.97 grams
Material Collected by Back-Up Filter:	0.36 grams
Total Material Collected:	18.33 grams

$$\text{Collection Efficiency} = \frac{\text{Material Collected by ESP}}{\text{Total Material Collected}} \times 100$$

$$= \frac{17.97 \text{ grams}}{18.33 \text{ grams}} \times 100$$

$$= 98.0\%$$

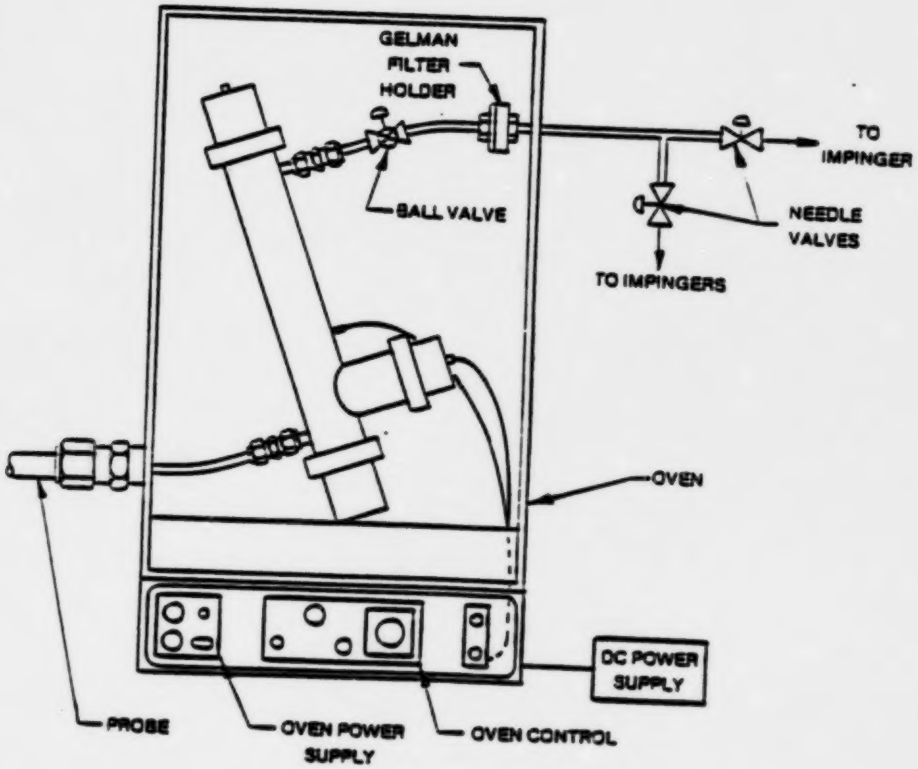

GELMAN
FILTER
HOLDER
TO
IMPINGER
BALL VALVE
NEEDLE
VALVES
TO IMPINGERS
OVEN
DC POWER
SUPPLY
PROBE
OVEN POWER
SUPPLY
OVEN CONTROL

Figure B-4. Schematic of ESP and Filter Configuration

Ten traverse points (Table B-2) were used to determine an average point of velocity (Figure B-5). Product gas sampling was performed at that point. Product gas flow rates were measured at the point of average velocity and are presented in Table B-3.

Figure B-6 shows the product gas sampling schedule. Note that in the approximate time period of 2130-2300 on December 13 the glass fiber filter behind the ESP was changed. As Table B-4 shows, the weight gain per sample volume of the second filter was considerably less than the weight gain per sample volume of the first. Also, measured ammonia, cyanide species, and moisture concentrations of the product gas were markedly less after the filter was changed. Apparently, a leak in the sampling system developed during the filter change. To account for the sampling system leak, an average dilution factor of 8.74 was determined for the sampling period after the filter change.

The dilution factor was determined by comparing the two filter weight gains per sample volume and moisture concentrations of the product gas before and after the filter change. A further justification of the dilution factor was developed by comparing carbon dioxide sorption into basic impingers before and after the filter change. Table B-4 presents the data and calculations used to determine the sampling dilution factor.

B.2.1 Ammonia

Four product gas samples for ammonia were collected with the impinger sampling train shown in Figure B-2. The impinger contents were:

1. 10% H_2SO_4(200 ml),
2. 10% H_2SO_4(200 ml),
3. dry, and
4. preweighed silica gel.

The gas temperature was maintained at 115°C (240°F) until the gas was filtered. The gas then passed through a stainless steel needle valve and Teflon tubing before entering the first impinger. At the end of each sampling run, the impinger contents were weighed and transferred to Nalgene sample bottles. The solutions were analyzed on-site by the distillation/titrimetric procedure. Table B-5 presents the ammonia concentrations in the product gas. The data summary in Table B-6 provides the sampling times and gas volumes for the ammonia sampling runs.

B.2.2 Hydrogen Cyanide and Hydrogen Thiocyanate

Product gas samples for hydrogen cyanide and hydrogen thiocyanate were also collected with an impinger sampling train (Figure B-2). The impinger solutions used were:

TABLE B-2. TRAVERSE POINTS USED TO PLOT AVERAGE POINT OF VELOCITY

POINT NUMBER	DISTANCE FROM INSIDE WALL (INCHES)
1	2.0
2	3.5
3	5.3
4	7.5
5	10.7
6	19.4
7	22.5
8	24.7
9	26.5
10	28.0

TABLE B-3. TEMPERATURE/VELOCITY DATA SUMMARY

DATE	TIME	TEMPERATURE °F	VELOCITY m/sec	VELOCITY (ft/sec)
12/13	1330	560	*	*
12/13	1630	430	13.4	(44.0)
12/13	1943	420	13.8	(45.3)
12/13	2117	420	14.3	(46.8)
12/14	0010	*	14.9	(48.9)
12/14	0030	*	11.3	(37.0)
12/14	0250	475	10.0	(33.0)

* Data not available.

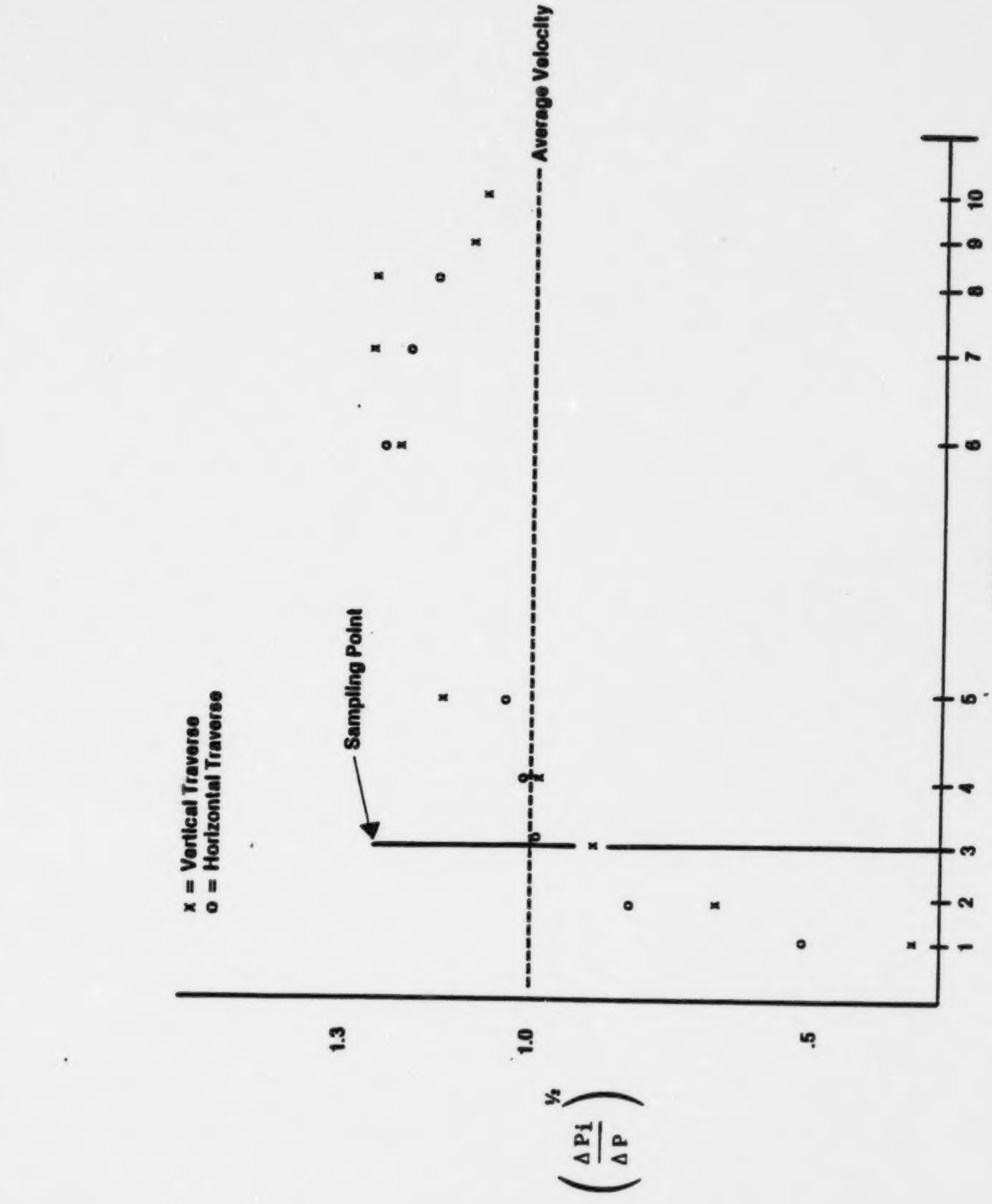


Figure B-5. Velocity Profile

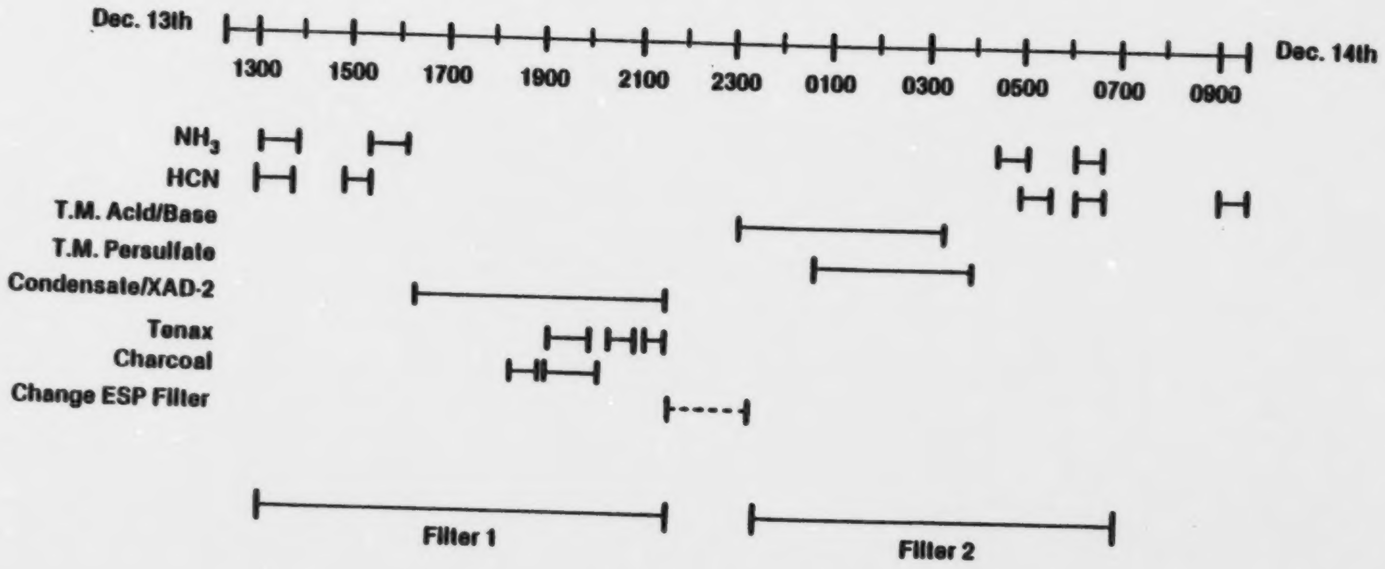


Figure B-6. Product Gas Sampling Schedule

TABLE B-4. DETERMINATION OF DILUTION FACTOR FOR PRODUCT GAS LOADINGS AND GAS SAMPLE VOLUMES

Filter Loadings:		Filter 1 (1205-2133, 12/13)	Filter 2 (2310,12/13-0632, 12/14)
Weight Gain		0.3291 grams	0.03128 grams
Sample Gas Volume		5.1084 Nm^3	4.2184 Nm^3
Loading		6.44 E4 $\mu g/Nm^3$	7.42 E3 $\mu g/Nm^3$
Dilution Factor	8.68		
Moisture Content:			
NH_3 #1		23.5 %	
NH_3 #2		23.7 %	
CN #1		26.5 %	
T.M. Acid/Base			3.6 %
T.M. Persulfate			2.0 %
Average		24.6 %	2.8 %
Dilution Factor:	8.79		
Average Dilution Factor	8.74		

CO_2 SORPTION OF BASIC IMPINGERS AS A BASIS OF JUSTIFICATION OF AVERAGE DILUTION FACTOR

CN #1		$0.0156 \frac{\text{scf } CO_2}{\text{scf P.G.}}$	
CN #2		$0.0242 \frac{\text{scf } CO_2}{\text{scf P.G.}}$	
T.M. Acid/Base			$0.00259 \frac{\text{scf } CO_2}{\text{scf P.G.}}$
Average		$0.0199 \frac{\text{scf } CO_2}{\text{scf P.G.}}$	
Dilution Factor:	7.68		

TABLE B-5. TRACE NITROGEN GAS SPECIES CONCENTRATIONS IN THE PRODUCT GAS

Sample	Impinger	μg/Impinger	Total μg	Sample Gas Volume Nm^3	$\mu g/Nm^3$	ppm (V/V)
NH_3 #1	1 2	200,000 ± 11,000 <6,000	200,000	0.2526	7.8E5	1120
NH_3 #2	1 2	205,000 ± 1,300 <6,000	205,000	0.2608	7.9E5	1130
NH_3 #3	1 2	<6,000 <6,000	<12,000	0.3137	<3.8E4	<55[c]
NH_3 #4	1	<6,000 <6,000	<12,000	0.2460	<4.9E4	<70[c]
HCN #1	1[a] 2[a] 1[b] 2[b]	34,100 ± 730 710 15,900 <370	50,700	0.3100	1.6E5	150
HCN #2	1[a] 2[a] 1[b] 2[b]	29,100 ± 310 280 5,400 <390	34,800	0.3050	1.1E5	100
HCN #3	1[a] 2[a] 1[b] 2[b]	350 ± 40 80 <380 <380	430	0.2582	1.7E3	1.5[c]
HCN #4	1[a] 2[a] 1[b] 2[b]	320 ± 100 110 <350 <360	430	0.2385	1.8E3	1.6[c]
HCN #5	1[a] 2[a] 1[b] 2[b]	35,800 ± 830 960 10,200 540	47,500	0.1802	2.6E5	240

[a] Analyzed as HCN

[b] Analyzed as SCN^- and converted to HCN

[c] Not to be considered representative of actual conditions

TABLE B-6. SAMPLING DATA SUMMARY

SUMMARY:	Flow Rate:	2.45 dry Nm³/sec (5030 dry scfm)
	Velocity:	13.0 m/sec (42.5 ft/sec)
	Duct ID:	74.3 cm (29.25 in) [.434 m²]
	Temperature:	232°C (450°F)
	Pressure:	100 kPa (14.5 psi)
	% Moisture:	25.6 %
	Sampling Period:	1305 hours 13 December - 0923 hours 14 December 1979

SAMPLING DATA:

SAMPLE	TIME	DATE	VOLUME[a] Nm³	Nm³	(SCF)	b (SCF)
NH_3 #1	1311-1344	12-13-79	.2526		(8.639)	
NH_3 #2	1525-1555	12-13-79	.2608	.	(8.919)	
NH_3 #3	0433-0502	12-14-79	.3137	.0359	(10.726)	(1.227)
NH_3 #4	0600-0630	12-14-79	.2460	.0282	(8.414)	(0.963)
HCN #1	1305-1340	12-13-79	.3100d		(10.601)	
HCN #2	1445-1520	12-13-79	.3050d		(10.431)	
HCN #3	0452-0526	12-14-79	.2582d	.0295	(8.829)	(1.010)
HCN #4	0600-0632	12-14-79	.2385d	.0273	(8.156)	(0.933)
HCN #5c	0900-0923	12-14-79	.1802d		(6.162)	
Trace Metals:						
Acid/Based	2310-0311	12-13,14-79	1.651	.1889	(56.589)	(6.458)
Persulfate	0045-0358	12-14-79	1.507	.1724	(51.543)	(5.897)
XAD-2 Resin	1619-2133	12-13-79	3.980		(136.110)	
Tenax #1	1918-2020	12-13-79	1070 scc[e]			
Tenax #2	2035-2105	12-13-79	550 scc			
Tenax #3	2112-2126	12-13-79	255 scc			
Charcoal #1	1825-1846	12-13-79	1020 scc			
Charcoal #2	1848-2000	12-13-79	2870 scc			

[a] Nm³, 25°C, 101 kPa, dry: SCF, 60°F, 14.7 psi, dry.

[b] Volume corrected using Average Dilution Factor of 8.74.

[c] Concurrent with particle size distribution.

[d] Corrected for absorbed CO_2.

[e] Standard cubic centimeters, 25°C, 101 kPa, dry.

1. 5% NaOH (200 ml),
2. 5% NaOH (200 ml),
3. dry, and
4. preweighed silica gel.

The product gas was sampled five times for cyanide species following the sampling procedure described for ammonia. After sampling, the impinger solutions were weighed, and an aliquot of the sample was stored in a sample bottle for CO_2 analysis. The samples were returned to Austin to be analyzed at Radian's main laboratory facilities. Analytical results were used to correct the sample volumes for CO_2 absorbed from the sample gas stream by the NaOH solution and thereby not metered as a portion of the sample volume.

The balance of the impinger solutions were then treated with lead acetate to precipitate sulfide, filtered, and transferred to sample bottles for storage. The samples were analyzed on-site for hydrogen cyanide by the distillation/colorimetric technique and for hydrogen thiocyanate by the extinction/colorimetric technique. Pertinent data for these samples are given in Tables B-5 and B-6.

B.2.3 Trace Elements

To sample the product gas for trace element content, two impinger sampling trains were run in parallel. After passing through the ESP and filter, the gas stream was split. Each leg consisted of a stainless steel needle valve followed by Teflon tubing leading to a glass impinger train.

The impinger contents of the first sampling train were of an acid/base configuration consisting of the following:

1. 10% HNO_3 (200 ml),
2. 10% HNO_3 (200 ml),
3. dry,
4. 5% NaOH (200 ml),
5. 5% NaOH (200 ml),
6. dry,
7. preweighed charcoal, and
8. preweighed silica gel.

The impinger contents of the second sampling train were:

1. 2M $(NH_4)_2S_2O_8$ + 0.2M $AgNO_3$ (200 ml),
2. 2M $(NH_4)_2S_2O_8$ + 0.2M $AgNO_3$ (200 ml),
3. dry,
4. preweighed charcoal, and
5. preweighed silica gel.

After sampling, the impinger contents were weighed and stored in sample bottles for analysis at Radian's Austin laboratories.

A portion of the particulates and organic material collected in the probe, ESP, and filter were also analyzed for trace element characterization. Sampling data pertinent to the trace element sampling are given in Table B-5.

B.2.4 Organics

Samples for organic characterization of the product gas were collected utilizing four methods:

- ESP,
- Condenser/XAD-2 resin,
- Tenax /silica gel, and
- Charcoal.

The four collection methods provided data for characterization of organic compounds in three fractions: high-boiling, medium-boiling, and low-boiling. High-boiling compounds are the most complex, while the low-boiling compounds are totally vaporous.

As described earlier, the ESP was used to trap oil and tar aerosols from the product gas sample. The ESP collected organic samples primarily in the high-boiling range. Sampling for organic vapors in the medium-boiling range was accomplished utilizing the condenser/resin canister system shown in Figure B-2. In this system, a condenser was followed by a canister containing approximately 400 cubic centimeters of XAD-2 resin. The condenser was maintained at a temperature less than 25°C. The analytical sample included both condensate collected in the condenser and vapors collected on the XAD-2 resin. Light-boiling organic vapors were collected on a Tenax /silica gel resin trap and on charcoal. The Tenax /silica gel and charcoal collection media were utilized to cover a broad range of possible organic vapor concentrations. The Tenax /silica gel is more ideally suited for low concentrations of light organic vapors, while the charcoal is more useful for sampling high concentrations of light organic vapors. Benzene, toluene, and xylene (BTX) are the light organic vaporous compounds of primary interest in this study.

Sample recovery of the ESP and condenser/XAD-2 resin consisted of removal and storage of the sample tars and oils or condensate, where possible. The hardware was rinsed with methylene chloride after removal of the primary sample; the rinse of each hardware item was stored individually. The XAD-2 resin was removed from the canister and stored under methylene chloride. All samples were stored in glass containers with Teflon -lined lids and kept at a temperature of 4°C. Samples were returned to Radian for analysis.

Light vapor samples were collected with Tenax /silica gel and charcoal tubes after the condenser and prior to the XAD-2 resin (Figure B-2). The sampling rates for the Tenax /silica gel and charcoal tubes were 18 and 50 cc/min, respectively. These samples and the XAD-2 resin samples were taken concurrently.

Gas was drawn through the Tenax /silica gel and charcoal tubes by means of a small diaphragm pump. The flow rate through the tubes was monitored using a Kurz mass flow meter. Gas volumes were determined from sample flow rate and sample time. A linear voltage output of the mass flow meter was monitored using a strip chart recorder. Samples times and volumes for these samples are presented in Table B-5.

B.2.5 Samples for Gas Chromatographic Analysis

The product gas was analyzed on-site by gas chromatography for:

- major (fixed) gases,
- gaseous sulfur species, and
- C_1-C_6 hydrocarbons.

The gas samples were collected at two locations. The first location was prior to the ESP clean-up system for the process GCs. The untreated gas was drawn through a glass fiber filter, in a heated stainless steel filter holder, followed by a Perma-Pure Drier . Teflon tubing was utilized to transport the sample gas from the drier to a Teflon -lined diaphragm pump, which was used to draw the sample and fill and pressurize the sample container. During sampling, a flow meter was connected to a 250- ml glass sampling bomb to monitor the sampling rate. The bombs were purged a minimum of three residence volumes, then pressurized to 170 kPa (10 psig) and immediately transported to the mobile laboratory for analysis. This sampling location became unavailable due to plugging of the sample line. Samples were then collected at the gas outlet of the ESP clean-up system used for product gas sampling. The gas collection system remained the same, except that the filter was not used since the sampling location provided filtered gas.

Previous studies conducted at the Bureau of Mines' Fort Snelling Gasifier in Minneapolis, Minnesota, have shown that the ESP clean-up system has no effect on sample integrity.

B.2.6 Particle Size Distribution

The particle size distribution of the product gas was characterized with a University of Washington Mark V cascade impactor. The impactor was inserted into the product gas streams as illustrated in Figure B-2. The Mark V cascade impactor aerodynamically separates particles into eleven size fractions. The gas stream passes through a series of perforated plates. The velocity of the gas stream is increased stepwise through each plate (stage) and, as the gas velocity increases, progressively smaller particles are impacted onto glass fiber substrates. After the final separation stage, the gas passes through a final filter. Aerosol oils and tars are collected along with particulates in this technique.

Product gas was drawn through the cascade impactor, through a heated probe, and then through an impinger train set up to determine HCN. An isokinetic sampling rate could not be maintained through the impactor because of the increased pressure drop due to the collection of aerosol oils and tars. Approximately 43% of the material collected was soluble in methylene chloride and, therefore, could be considered to be liquid aerosol material.

Table B-7 summarizes the impactor results. Figures B-7 and B-8 are plots of the total loading and CH_2Cl_2 insoluble loading, respectively.

B.3.0 IN-PLANT FUGITIVE EMISSIONS

In-plant fugitive samples were collected above the gasifier deck near the lock hopper system to characterize organic vapors. Three collection media were used:

- Tenax ,
- Tenax /silica gel, and
- Charcoal.

Medium to heavy organic vapors were collected on 2 grams of Tenax contained in a 1.3-centimeter by 15.2-centimeter (1/2-inch by 6-inch) glass tube. One sample was collected over a continuous 24-hour period.

High-level concentrations of benzene, toluene, and xylene (BTX) were collected in charcoal tubes. Low-level BTX concentrations were determined using glass-lined steel tubes containing Tenax and silica gel. Sample times and volumes of these samples are listed in Table B-8.

In addition to the above samples, in-plant areas were surveyed for hydrocarbons using an Organic Vapor Analyzer (OVA). This instrument is basically a gas chromatograph with a flame ionization detector and an empty column. The OVA, which is battery-operated, has a replaceable hydrogen supply for the detector; air is the detector oxygen source.

Hydrocarbon sampling with the OVA was conducted in walk areas in the gasifier building and on top of the gasifier during the poking operation. OVA sampling was also conducted on an effluent stream of the coal bin to check for product gas leakage through the coal feed system into the bin. The OVA hydrocarbon sampling data are presented in Table B-9.

Riley has two carbon monoxide monitors mounted on interior walls of the gasifier building. One is mounted on the west wall of the ground floor, below the gasifier reactor. The other CO monitor is located on the north wall of the top level of the gasifier. The poking operation is performed on this level. Readings of the monitors were recorded occasionally during the sampling period. Table B-10 presents the CO monitor readings.

TABLE B-7. IMPACTOR RESULTS SUMMARY

Impactor Results Summary
Sample Ident: PSD #1

Sampling Location: Product Gas
Type of Impactor: University of Washington
Impactor Substrate: Glass Fiber
Date: 12/14/79 (MMDDYY)

	TIME START: 9:00 (HHMM)	TIME FINISH: 9:23 (HHMM)
Average Flue Gas Temperature	520.0 (F)	271.1 (C)
Flue Gas Pressure (Absolute)	29.61 in. HG	75.22 cm HG
Flue Gas Static Pressure	.20 in. H_2O	.508 cm H_2O
Flue Gas Molecular Weight (Wet)	22.65 lb/lb-mole	22.6529 gm/gm-mole
Flue Gas Viscosity	168 E-4 lb/sec/ft^3	250 E-3 poise
Flue Gas Mean Free Path	550 E-5 inches	140 E-4 cm
Flue Gas Percent Moisture	28.85 %	28.85 %
Average Flue Gas Velocity	43.9017 FPS	13.3813 m/s
Average Flue Gas Flow Rate	12292 ACFM 4662 DSCFM	348 m^3/min 132 m^3/min
Volume of Flue Gas Samples (Dry, Standard Conditions)	6.1710 DSCF	.1748 m^3
Test Duration	23 min	23 min
Total Impactor Catch	.111 E-2 lbs	.503 E3 mg
Sampling Rate at Impactor	.812 ACFM	.023 cm^3/sec
Temperature at Which Particulate Collected	520.0 (F)	271.1 (C)
Percent Isokinetic	56.1 %	56.1 %
Nominal Mass Concentration	.126 E1 gr/DSCF .180 E-3 lbs/DSCF	.288 E1 gms/m^3

(Continued)

TABLE B-7. Continued

Impactor Results Summary
Sample Ident: PSD #1

Nominal Mass Concentration

126 E1 gr/DSCF
180 E-3 lbs/DSCF

.288 E1 gms/m^3

Stage #	Stage DP_{50} (Interval Endpoint)	Mass Fraction	Mass Fraction Less Than	Interval Geometric Midpoint	DM/DLOG DP Dry. Stand. Conditions gr/DSCF	DM/DLOG DP Dry. Stand. Conditions gms/m^3
1	27.07	.0565	.9435	36.7888	.267 E0	.610 E0
2	11.76	.0121	.9314	17.8435	.419 E-1	.958 E-1
3	4.45	.0242	.9072	7.2356	.721 E-1	.165 E0
4	2.17	.0220	.8851	3.1088	.889 E-1	.203 E0
5	1.18	.0186	.8665	1.6012	.884 E-1	.202 E0
6	.79	.0675	.7990	.9637	.481 E0	.110 E1
7	.61	.1891	.6099	.6902	.209 E1	.479 E1
8	.46	.2550	.3549	.5307	.279 E1	.639 E1
9	.36	.2518	.1031	.4068	.273 E1	.625 E1
10	.30	.0903	.0128	.3244	.141 E1	.322 E1
11	.24	.0102	.0026	.2657	.138 E0	.315 E0
Final Filter		.0026	.0000	.0345	.195 E-2	.446 E-2

(Continued)

TABLE B-7. Continued

Impactor Results Summary
Sample Ident: PSD #1 CH_2Cl_2 Insoluble

Sampling Location: Product Gas
Type of Impactor: University of Washington
Impactor Substrate: Glass Fiber
Date: 12/14/79 (MMDDYY)

	TIME START: 9:00 (HHMM)	TIME FINISH: 9:23 (HHMM)
Average Flue Gas Temperature	520.0 (F)	271.1 (C)
Flue Gas Pressure (Absolute)	29.61 in. HG	75.22 cm HG
Flue Gas Static Pressure	.20 in. H_2O	.508 cm H_2O
Flue Gas Molecular Weight (Wet)	22.65 lb/lb-mole	22.6529 gm/gm-mole
Flue Gas Viscosity	168 E-4 lb/sec/ft²	250 E-3 poise
Flue Gas Mean Free Path	550 E-5 inches	140 E-4 cm
Flue Gas Percent Moisture	28.85 %	28.85 %
Average Flue Gas Velocity	43.9017 FPS	13.3813 m/s
Average Flue Gas Flow Rate	12292 ACFM 4662 DSCFM	348 m³/min 132 m³/min
Volume of Flue Gas Samples (Dry, Standard Conditions)	6.1710 DSCF	.1748 m³
Test Duration	23 min	23 min
Total Impactor Catch	634 E-3 lbs	.287 E3 mg
Sampling Rate at Impactor	.812 ACFM	.023 cm³/sec
Temperature at Which Particulate Collected	520.0 (F)	271.1 (C)
Percent Isokinetic	56.1 %	56.1 %
Nominal Mass Concentration	.719 E0 gr/DSCF .103 E-3 lbs/DSCF	.164 E1 gms/m³

(Continued)

TABLE B-7. Continued

Impactor Results Summary
Sample Ident: PSD #1 CH_2Cl_2 Insoluble

Nominal Mass Concentration 719 E0 gr/DSCF .164 E1 gms/m³
130 E-3 lbs/DSCF

Stage #	Stage DP_{50} (Interval Endpoint)	Mass Fraction	Mass Fraction Less Than	Interval Geometric Midpoint	DM/DLOG DP Dry. Stand. Conditions gr/DSCF	gms/m³
1	27.07	.0847	.9153	36.7888	.228 E0	.523 E0
2	11.76	.0211	.8942	17.8435	.419 E-1	.958 E-1
3	4.45	.0423	.8519	7.2356	.721 E-1	.165 E0
4	2.17	.0330	.8189	3.1088	.760 E-1	.174 E0
5	1.18	.0237	.7953	1.6012	.643 E-1	.147 E0
6	.79	.0678	.7274	.9637	.276 E0	.632 E0
7	.61	.1704	.5570	.6902	.108 E1	.247 E1
8	.46	.2097	.3473	.5307	.131 E1	.300 E1
9	.36	.2283	.1190	.4068	.142 E1	.324 E1
10	.30	.1003	.0187	.3244	.894 E0	.205 E1
11	.24	.0141	.0045	.2657	.109 E0	.250 E0
Final Filter		.0046	.0000	.0345	.195 E-2	.446 E-2

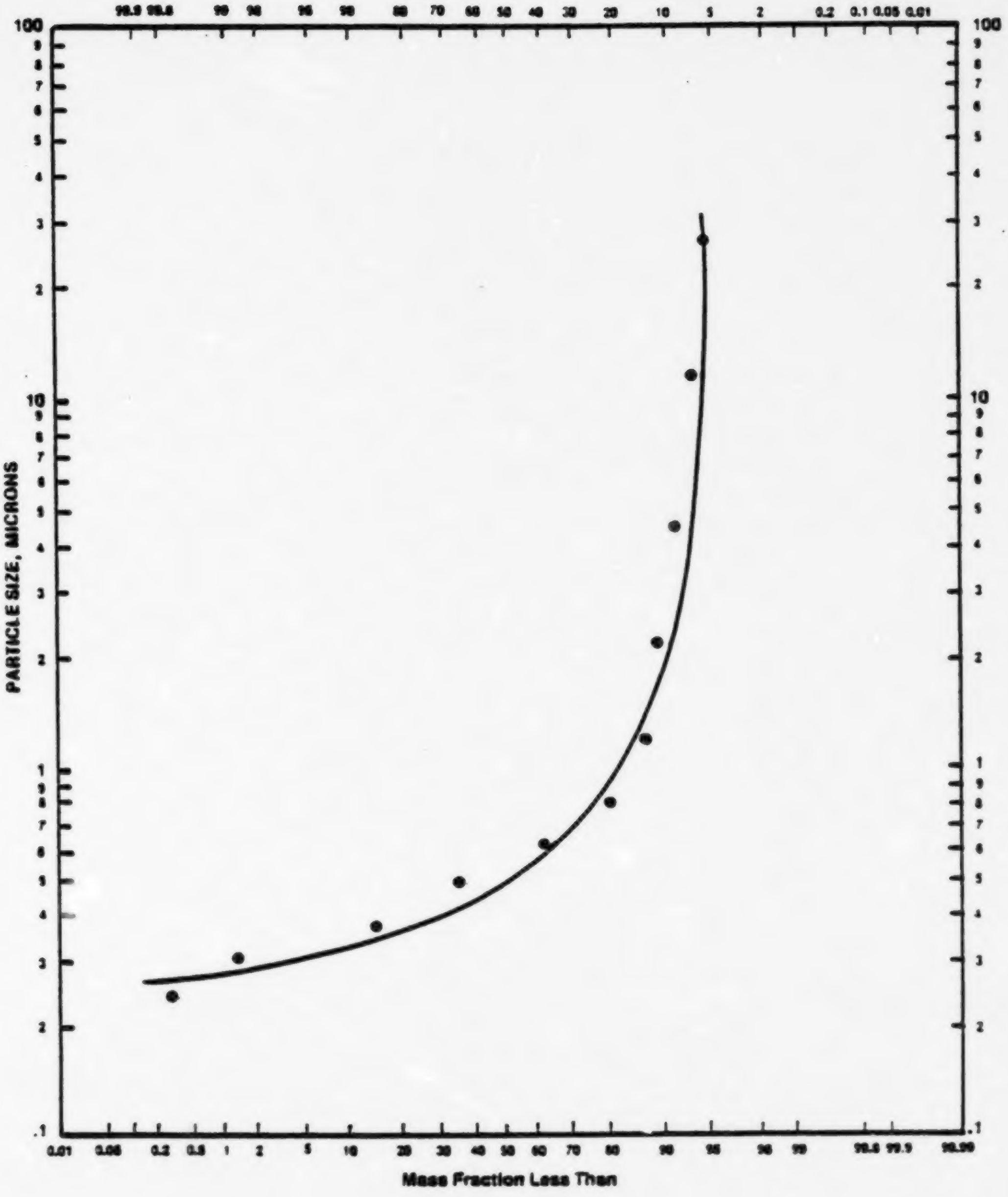


Figure B-7. Total Loading of Product Gas - December 14, 1979

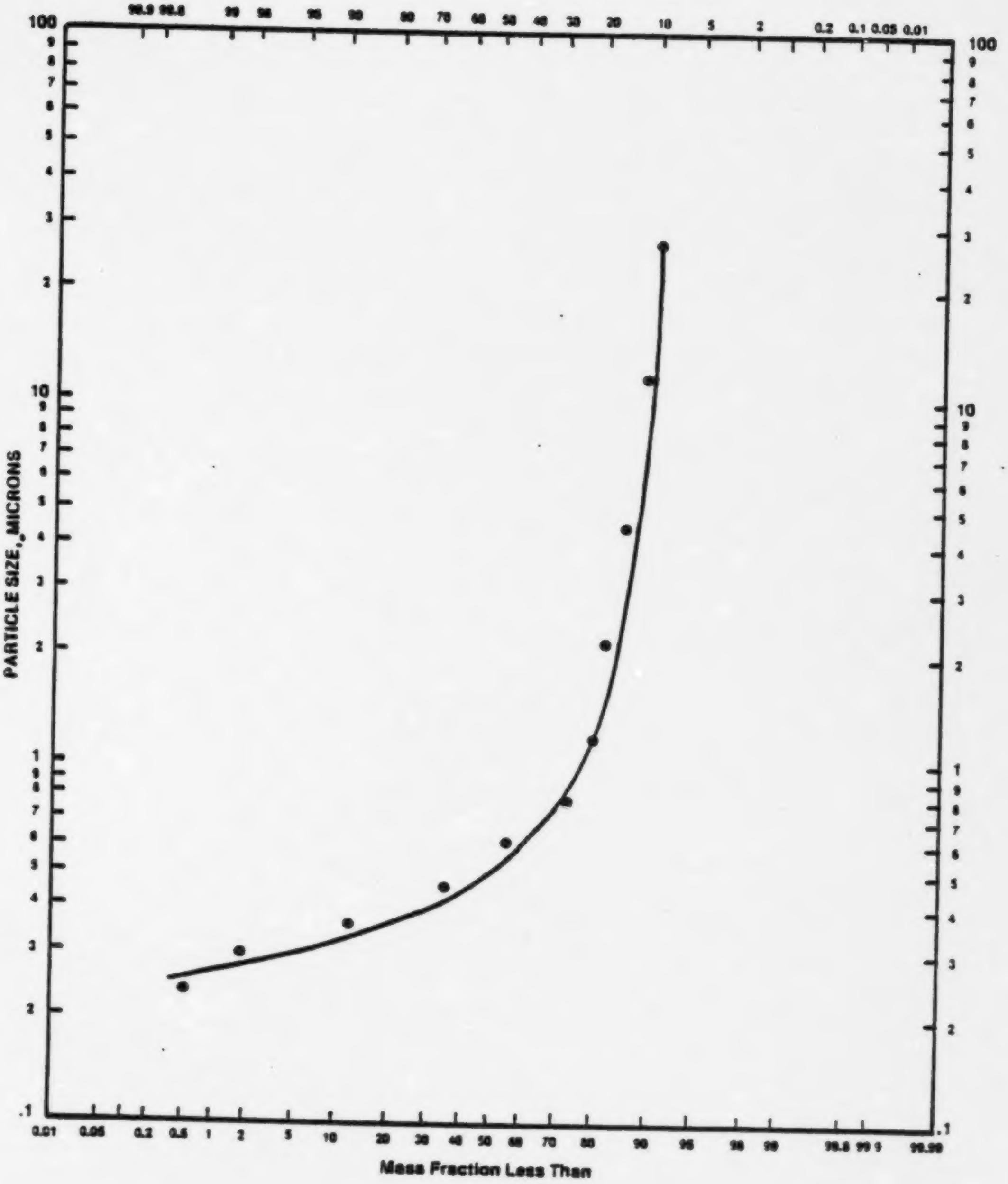


Figure B-8. CH_2Cl_2 Insoluble Loading of Product Gas - December 14, 1979

TABLE B-8. IN-PLANT FUGITIVE SAMPLING DATA

Sample I.D.	Date	Time	Volume
Tenax	12/13, 12/14	0930 - 0925	3.849 Nm^3 (131.96 SCF)[a]
Tenax /Silica Gel	12/14	0255 - 0310	282 Ncc[b]
	12/14	0325 - 0530	2200 Ncc[b]
Charcoal	12/14	0255 - 0310	547 Ncc[b]
	12/14	0325 - 0530	5500 Ncc[b]

[a] Nm^3, 25°C, 101 kPa (dry); SCF, 60°F, 14.7 psi (dry).
[b] Ncc, 25°C, 101 kPa (dry).

TABLE B-9. ORGANIC VAPORS ANALYSIS

Date	Time	Location	Concentration (ppm as CH_4)
12/13	~1100 hours	Gasifier Building - all walkways	1.5 ppm
12/13	~2200 hours	Gasifier Building - all walkways	1 ppm
12/13	~2200 hours	Gasifier Building - top of gasifier during poking operation	1 ppm
12/13	~2223 hours	Coal Bin - 5-centimeter (2-inch) gate valve on top	5 - 6 ppm

TABLE B-10. CARBON MONOXIDE MONITOR READINGS

Date	Time	Monitor 1[*]	Monitor 2[+]
12/13	1100		20 ppm
12/13	1500	1 ppm	
	1502		12 ppm
	1506		15 ppm
	1750	1 ppm	24 ppm
	1808		1 ppm
	2213		<0 ppm
12/14	0035		<0 ppm
	0235	1 ppm	<0 ppm

[*] Located in gasifier bulding on ground level, west wall.

[+] Located in gasifier building on gasifier poke hole level, north wall.

B.4.0 POKEHOLE

Pokeholes on the top level of the gasifier allow the insertion of metal rods into the gasification zone to check bed depth and fire zone thickness. Sampling was conducted to characterize emissions from a poke hole during the poking operation.

An apparatus was designed to simulate a poke rod in position and allowed the measurement of the gaseous emission flow rate and the collection of a gaseous sample for analysis. Figure B-9 shows this sampling apparatus. It consisted of a metal pipe welded to a metal ball mounted into a socket which in turn was mounted into the top of the gasifier. The pipe was sealed with a gate valve. Prior to the gate valve, a 45° pipe tee was mounted in the pipe so that access to the poke hole though the 45° tee was towards the pokehole. During poking, nitrogen was injected into the gasifier through the 45° tee to prevent the emission of product gas.

The gaseous emission was analyzed for major gases using a gas chromatograph with a thermal conductivity detector. The sampling data and analytical results are presented in Table B-11.

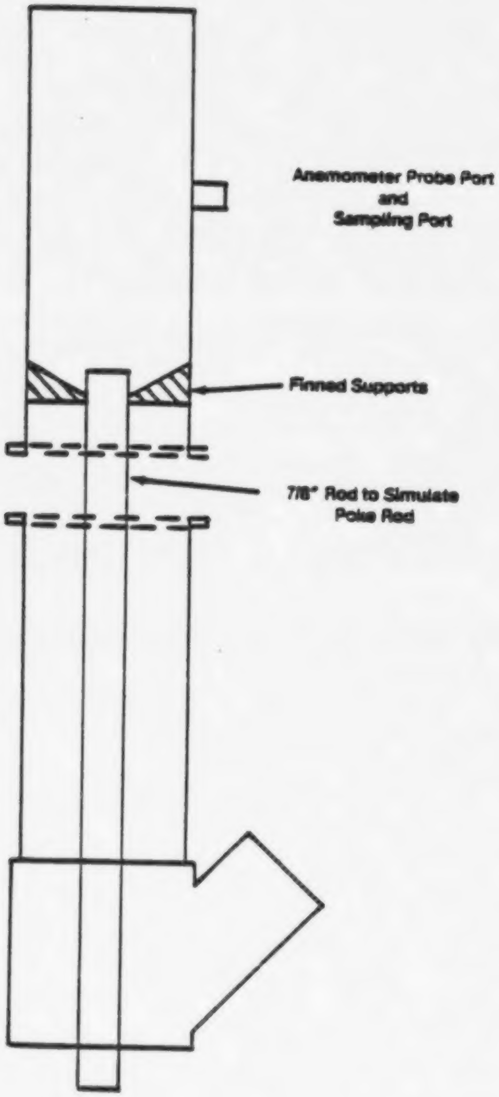

Anemometer Probe Port
and
Sampling Port
Finned Supports
7/8" Rod to Simulate
Poke Rod

Figure B-9. Pokehole Sampling Apparatus

TABLE B-11. POKEHOLE DISCHARGE DURING SIMULATED POKING OPERATION

Date:	12-14	
Time:	0645 hours	
Flow Rate:	0.22 m^3/sec (actual)	
Gas Analysis:	N_2	95.4%
	H_2	1.1%
	O_2	0.2%
	CO_2	Below Detection Limit
	CH_2	Below Detection Limit
	CO_2	Below Detection Limit

B.5.0 SOLIDS AND LIQUIDS

The solid and liquid streams sampled were:

- lignite (1),
- gasifier ash (5),
- cyclone dust (6),
- ash pan water (3), and
- service water (8).

B.5.1 Lignite

Dump trucks delivered lignite to the plant and dumped it into a pit. From there the lignite was conveyed by a series of enclosed conveyors up to the coal storage bin above the gasifier.

The lignite samples were collected in one-gallon polypropylene bags as the lignite fell from the truck into the pit. The bags were fully opened and passed through the falling lignite on a line parallel to the truck. Variations in particle size were apparent across the falling lignite stream. This sampling technique provided for the collection of a sample more representative of the average lignite.

One sample was collected from each dump truck load of lignite. The bags were sealed after collection of the samples and were returned to Radian for analysis.

B.5.2 Gasifier Ash

The ash pan is a stationary vessel located directly below the reactor vessel, which normally rotates. Ash is removed with a shovel-like device called the "plow", which rides in a rail attached to the reactor during normal operation. To remove ash, the plow is locked in position to the ash pan. The rotation of the reactor forces ash up into the plow, and then the ash is carried downward through a chute by the ash pan water expelled with the ash. The ash is dewatered and conveyed into hoppers for weighing and disposal. Ash was normally removed every two to four hours.

Samples for trace element analysis, leaching studies and organic analysis were collected each time ash was removed from the gasifier. These samples were taken from the hoppers by filling a sample bottle with material from random areas of the hopper. Samples for trace element analysis and leaching studies were collected and stored in one-liter polyethylene bottles, and those for organic analysis in one-liter glass jars with Teflon seals.

B.5.3 Cyclone Dust

During the sampling period, no cyclone dust was collected because the discharge leg of the cyclone plugged up early in the demonstration run. After process operation was completed, the cyclone was emptied and the collected char weighed. Riley-Stoker personnel collected four samples of the cyclone dust in glass quart jars and sent them to Radian for analysis.

B.5.4 Ash Pan Water

A water level is maintained in the ash pan to serve as a seal for the reactor vessel. Samples of this water were collected directly from the ash pan at 4-hour intervals. Samples for wastewater and trace element analyses were collected and stored in polyethylene bottles, and those for organic analysis were collected and stored in glass jars. Then the samples were taken to the on-site laboratory and preserved for analysis.

The discharge rate of ash pan water was determined during normal operation of the gasifier by collecting it in a vessel of known volume and monitoring the time required to fill the vessel. Table B-12 presents the flow rate data.

B.5.5 Service Water

Service water samples were collected from a faucet located on the gasifier level. Samples for wastewater and trace element analyses were collected and stored in polyethylene bottles, and samples for organic analysis were collected and stored in glass jars.

TABLE B-12. ASH PAN WATER DISCHARGE DURING NORMAL OPERATION

Date	Time	Flow rate (liters/sec)
12-13	1110-1105	2.18
		2.32
		2.23
		2.14
		2.07
		2.07

Average Flow rate = 2.17 liters/sec
Water temperature = 18°C

B.6.0 SAMPLE LOG

Table B-13 presents a list of samples collected, the time and date of collection, and the analysis performed on each.

TABLE B-13. SAMPLE LOG

Sample No.	Description	Date	Time	Analysis
RM-1	DI Water Blank	12-12	1825	Hold
RM-2	Product gas ESP Filter	12-13		Add RM-57 and 63, extract TE and organics
RM-3	Ash Pan Water	12-13	0850	pH, $S^=$ on-site, hold
RM-4	Ash Carry Over Water	12-13	1010	pH, $S^=$, TE
RM-5	Service Water	12-13	1020	Water quality, TE, organics
RM-6	Ash Pan Water	12-13	1100	pH, $S^=$ on-site, hold
RM-7	HCN#1-1st Imp Product Gas	12-13	1344	Analyzed on-site
RM-8	HCN#1-2nd Imp Product Gas	12-13	1344	Analyzed on-site
RM-9	Ash Pan Water	12-13	1415	pH, $S^=$ on-site, hold
RM-10	NH_3 #1-1st Imp Product Gas	12-13	1344	Analyzed on-site
RM-11	NH_3 #1-2nd Imp Product Gas	12-13	1344	Analyzed on-site
RM-12	HCN#2-1st Imp Product Gas	12-13	1520	Analyzed on-site
RM-13	HCN#2-2nd Imp Product Gas	12-13	1520	Analyzed on-site
RM-14	Service Water	12-13	1530	pH, $S^=$ on-site, hold
RM-15	NH_3 #2-1st Imp Product Gas	12-13	1555	Analyzed on-site
RM-16	NH_3 #2-2nd Imp Product Gas	12-13	1555	Analyzed on-site
RM-17	Ash Pan Water	12-13	1715	pH, $S^=$ on-site, hold
RM-18	Ash Pan Water	12-13	1930	Water quality, TE, organics
RM-19	Ash Pan Water	12-13	2145	pH, $S^=$ on-site, hold
RM-20	XAD-2 Resin: Product Gas	12-13	2133	Extract, organics
RM-21	Condensate: Product Gas	12-13	2133	Add RM-22, extract, organics
RM-22	Condensate CH_2Cl_2 Rinse Product Gas	12-13	2133	Add RM-21, extract, organics
RM-23	Ash Pan Water	12-14	0000	Water quality, TE, organics
RM-24	Charcoal Tube #1: , Product Gas (1000 cc)	12-13	1846	Hold for data review
RM-25	Charcoal Tube #2: , Product Gas (2500 cc)	12-13	2000	Hold for data review

(Continued)

TABLE B-13. Continued

Sample No.	Description	Date	Time	Analysis
RM-26	Tenax #1: Product Gas (1000 cc)	12-13	2020	Hold for data review
RM-27	Tenax #2: Product Gas (500 cc)	12-13	2105	Thermal desorption, GC
RM-28	Tenax #3: Product Gas (250 cc)	12-13	2126	Hold for data review
RM-29	Service Water	12-14	0100	pH, S$^=$ on-site, hold
RM-30	Ash Pan Water	12-14	0300	pH, S$^=$ on-site, hold
RM-31	TM #1 Acid: Product Gas	12-14	0311	Add RM-32, TE
RM-32	TM #2 Acid: Product Gas	12-14	0311	Add RM-31, TE
RM-33	TM #1 Base: Product Gas	12-14	0311	Add RM-34, TE
RM-34	TM #2 Base: Product Gas	12-14	0311	Add RM-33, TE
RM-35	TM Charcoal: Product Gas	12-14	0311	Extract, TE
RM-36	TM #1 Persulfate: Product Gas	12-14	0358	TE
RM-37	TM #2 Persulfate: Product Gas	12-14	0358	TE
RM-38	TM Charcoal: Product Gas	12-14	0358	Extract, TE
RM-39	HCN#3-1st Imp Product Gas	12-14	0526	Analyzed on-site
RM-40	HCN#3-2nd Imp Product Gas	12-14	0526	Analyzed on-site
RM-41	NH$_3$ #3-1: Product Gas	12-14	0502	Analyzed on-site
RM-42	NH$_3$ #3-2: Product Gas	12-14	0502	Analyzed on-site
RM-43	Charcoal Tube Blank: In-Plant Fugitive	12-14	0200	Thermal desorption, GC
RM-44	Charcoal Tube: In-Plant Fugitive (500 cc)	12-14	0255	Hold for data review
RM-45	Charcoal Tube: In-Plant Fugitive (5000 cc)	12-14	0325	Extraction, GC
RM-46	Tenax /Silica Gel: In-Plant Fugitive	12-14	0200	Thermal desorption, GC

(Continued)

TABLE B-13. Continued

Sample No.	Description	Date	Time	Analysis
RM-47	Tenax /Silica Gel: In-Plant Fugitive (250 cc)	12-14	0255	Hold for data review
RM-48	Tenax /Silica Gel: In-Plant Fugitive (2000 cc)	12-14	0325	Hold for data review
RM-49	Ash Pan Water	12-14	0640	Water quality, TE, organics
RM-50	ESP Tar Solids: Product Gas	12-14		Add RM-58, extract, TE, organics
RM-51	Probe + Nozzle Catch: Product Gas	12-14		Add RM-56, extract, TE, organics
RM-52	HCN#4-1st Imp Product Gas	12-14	0632	Analyzed on-site
RM-53	HCN#4-2nd Imp Product Gas	12-14	0632	Analyzed on-site
RM-54	NH_3 #4-1st Imp Product Gas	12-14	0630	Analyzed on-site
RM-55	NH_3 #4-2nd Imp Product Gas	12-14	0630	Analyzed on-site
RM-56	CH_2Cl_2 Probe + Nozzle Rinse Product Gas	12-14		Add RM-51, extract, TE, organics
RM-57	ESP Filter #2: Product Gas	12-14		Add RM-2 + 63, extract, TE, organics
RM-58	CH_2Cl_2 ESP Rinse: Product Gas	12-14		Add RM-50, extract, TE, organics
RM-59	Tenax /In-Plant Fugitive	12-14		Thermal desorption, GC
RM-60	HCN#5-1st Imp Product Gas	12-14	0923	Analyzed on-site
RM-61	HCN#5-2nd Imp Product Gas	12-14	0923	Analyzed on-site
RM-62	Large Tenax Blank	12-14		Extraction, GC
RM-63	CH_2Cl_2 Rinse, ESP to Filter	12-14		Add RM-2 + 57, extract, TE, organics
RM-64	Coal	12-12	0730	Hold
RM-65	Coal	12-12	0845	Hold
RM-66	Coal	12-12	1100	Hold
RM-67	Coal	12-12	1245	Hold

(Continued)

TABLE B-13. Continued

Sample No.	Description	Date	Time	Analysis
RM-68	Coal	12-12	1345	Hold
RM-69	Coal	12-12	1615	Hold
RM-70	Coal	12-12	2245	Hold
RM-71	Coal	12-12	2300	Hold
RM-72	Coal	12-12	2350	Hold
RM-73	Coal	12-13	0700	Ultimate/proximate, TE
RM-74	Coal	12-13	0900	Hold
RM-75	Coal	12-13	1100	Ultimate/proximate
RM-76	Coal	12-13	1215	Ultimate/proximate
RM-77	Coal	12-13	1415	Ultimate/proximate, TE
RM-78	Coal	12-13	1630	Hold
RM-79	Coal	12-13	1800	Hold
RM-80	Gasifier Ash	12-13	1845	Hold
RM-81	Coal	12-13	1945	Ultimate/proximate
RM-82	Coal	12-13	2045	Ultimate/proximate
RM-83	Coal	12-13	2345	Hold
RM-84	Coal	12-14	0730	Hold
RM-85	Coal	12-14	1000	Hold
RM-86	Coal	12-14	1145	Hold
RM-87	Coal	12-14	1330	Hold
RM-88	Coal	12-14	2030	Hold
RM-89	Coal	12-14	2145	Hold
RM-90	Gasifier Ash	12-12	1300	Hold
RM-91	Gasifier Ash	12-13	1030	Hold
RM-92	Gasifier Ash	12-13	1030	Hold
RM-93	Gasifier Ash	12-13	1430	Hold
RM-94	Gasifier Ash	12-13	1430	Hold
RM-95	Gasifier Ash	12-13	1845	Ultimate/proximate composite
RM-96	Gasifier Ash	12-13	1845	Hold

(Continued)

TABLE B-13. Continued

Sample No.	Description	Date	Time	Analysis
RM-97	Gasifier Ash	12-13	1845	Hold
RM-98	Gasifier Ash	12-14	0015	Ultimate/proximate composite
RM-99	Gasifier Ash	12-14	0015	Hold
RM-100	Gasifier Ash	12-14	0015	Hold
RM-101	Gasifier Ash	12-14	0015	Hold
RM-102	Gasifier Ash	12-14	0530	Hold
RM-103	Gasifier Ash	12-14	0530	Hold
RM-104	Gasifier Ash	12-14	0530	Hold
RM-105	Gasifier Ash	12-14	0530	Hold
RM-106	Gasifier Ash	12-14	0915	Hold
RM-107	Gasifier Ash	12-14	0915	Hold
RM-108	Gasifier Ash	12-14	0915	Hold
RM-109	Gasifier Ash	12-14	0915	Hold
RM-110	Gasifier Ash	12-14	1015	Hold
RM-111	Gasifier Ash	12-14	1015	Hold
RM-112	Gasifier Ash	12-14	1015	Hold
RM-113	Gasifier Ash	12-14	1015	Hold
RM-114	Gasifier Ash	12-14	1345	Hold
RM-115	Gasifier Ash	12-14	1345	Hold
RM-116	Gasifier Ash	12-14	1345	Hold
RM-117	Gasifier Ash	12-14	1345	Hold
RM-118	Gasifier Ash	12-14	1530	Hold
RM-119	Gasifier Ash	12-14	1530	Hold
RM-120	Gasifier Ash	12-14	1530	Hold
RM-121	Gasifier Ash	12-14	1530	Hold
RM-122	Gasifier Ash	12-14	1845	Hold
RM-123	Gasifier Ash	12-14	1845	Hold
RM-124	Gasifier Ash	12-14	1845	Hold
RM-125	Gasifier Ash	12-14	1845	Hold
RM-126	Gasifier Ash	12-14	2330	Ultimate/proximate, TE, organics

(Continued)

TABLE B-13. Continued

Sample No.	Description	Date	Time	Analysis
RM-127	Gasifier Ash	12-14	2330	Hold
RM-128	Gasifier Ash	12-14	2330	Hold
RM-129	Gasifier Ash	12-14	2330	Hold
RM-130	Coal	12-12	0800	Hold
RM-131	Coal	12-12	0945	Hold
RM-132	Coal	12-13	1315	Hold
RM-133	Coal	12-13	1515	Hold
RM-134	Coal	12-13	1730	Hold
RM-135	Coal	12-13	2230	Hold
RM-136	Coal	12-14	0600	Hold
RM-137	Coal	12-14	0845	Hold
RM-138	Coal	12-14	1100	Hold
RM-139	Coal	12-14	1200	Hold
RM-140	Coal	12-14	1245	Hold
RM-141	Coal	12-14	1430	Hold
RM-142	Coal	12-14	1515	Hold
RM-143	Coal	12-14	1630	Hold
RM-144	Coal	12-14	1715	Hold
RM-145	Coal	12-14	1815	Hold
RM-146	Coal	12-14	1945	Hold
RM-147	Gasifier Ash			Ultimate/proximate, TE,
RM-148	Gasifier Ash			Hold
RM-149	Gasifier Ash			Ultimate/proximate
RM-150	Gasifier Ash			Hold
RM-151	Gasifier Ash			Hold
RM-152	Gasifier Ash			Hold
RM-153	Cyclone Dust			Ultimate/proximate, TE, organics

(Continued)

TABLE B-13. Continued

Sample No.	Description	Date	Time	Analysis
RM-154	Cyclone Dust			Ultimate/proximate, TE, organics
RM-155	Cyclone Dust			Hold
RM-156	Cyclone Dust			Hold
RM-157	Cyclone Dust			Hold
RM-158	ESP Liquid: Process GC	12-13		Weigh, ultimate/proximate
RM-159	Charcoal	Rec'd from Riley		Ultimate/proximate
RM-160	Gasifier Ash	Rec'd from Riley		Ultimate/proximate

APPENDIX C
ANALYTICAL TECHNIQUES

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C.1.0 INTRODUCTION

Radian Corporation has conducted an environmental assessment of the Riley Gas Producer, a low-Btu coal gasification process. This appendix describes the analytical techniques and methodologies used for the analyses of samples collected for the assessment of the gasifier.

C.2.0 WASTEWATER PARAMETERS AND IONIC SPECIES ANALYSES

C.2.1 Ammonia

Ammonia in the sulfuric acid impinger solutions and water samples was determined on-site by the distillation/titrimetric procedure (Ref. C-1). The sample was initially distilled into an indicating boric acid absorbing solution. The collected distillate was titrated with standard sulfuric acid. The detection limit for the procedure is 1.4 µg/ml ammonia. This is equivalent to 1.7 ppm ammonia by volume collected from 0.28 SCM of sampled gas in 200 ml of impinger solution.

C.2.2 Cyanide

Cyanide was determined on-site by the distillation/colorimetric procedure (Ref. C-1). Interfering sulfide was precipitated from the caustic impinger solutions and water samples with lead nitrate. An acid reflux distillation procedure was used to remove interferences. Distilled hydrogen cyanide was collected in a caustic solution, and converted to cyanogen chloride by reaction with chloramine-T. Following complete conversion, pyridine-barbituric acid reagent was added to produce a red-blue dye with absorbance at 578 nm. Cyanide in the range of 1-10 g was determined spectrophotometrically by comparison with a standard calibration curve generated from potassium cyanide standard solutions. The detection limit for the procedure is .02 µg/ml cyanide. This is equivalent to 0.15 ppm hydrogen cyanide by volume collected from 0.28 SCM of sampled gas in 200 ml of impinger solution.

C.2.3 Thiocyanate

Thiocyanate was determined colorimetrically using the same samples used for cyanide analysis. An aliquot of the sample solution was extracted with chloroform to remove organic compounds. A solution of copper and pyridine was added to the aqueous layer to form a copper dithiocyanatopyridine complex. The complex was extracted with chloroform and determined spectrophotometrically at 407 nm by comparison to a calibration curve generated from standard solutions. The detection limit for the procedure is 1 µg/ml thiocyanate. This is equivalent to 3.2 ppm thiocyanate by volume collected from 0.28 SCM of sampled gas in 200 ml of impinger solution.

C.2.4 Chloride

A Dionex Model 14 ion chromatograph with a conductivity detector was used to measure chloride concentrations in aqueous samples. An injection volume of 100 µl was used. The sample was eluted with 0.003M Na_2CO_3/0.003M $NaHCO_3$. A detection limit of 0.1 ppm was reported. Sample response was compared to a standard curve.

C.2.5 Fluoride

Baker (Ref. C-2), Bauman (Ref. C-3), and Thomas (Ref. C-4), describe standard addition techniques utilizing a specific ion electrode for the measurement of fluoride in aqueous samples. A citrate buffer was added to the sample to buffer both pH and ionic strength. Fluoride bound in metal complexes was released by the buffer. Fluoride concentration was related to potential changes which were measured using an Orion Model 94-09A solid state fluoride electrode and an Orion Model 701A ion analyzer meter. A detection limit of 0.05 ppm was reported.

C.2.6 Phosphate

Phosphate was determined as the molybdenum blue complex by the standard method (Ref. C-1). The aqueous sample was reacted with acidic ammonium molybdate to form a yellow phosphomolybdate complex. The addition of ascorbic acid developed the blue color which was measured spectrophotometrically and compared to a standard calibration curve. A detection limit of 0.5 ppm was reported.

C.2.7 Nitrate

Nitrate was determined colorimetrically using the standard method (Ref. C-1). Nitrate reacts with chromotropic acid to form a yellow reaction product which was measured spectrophotometrically at 410 nm and compared to a set of standards. A detection limit of 0.1 ppm was reported.

C.2.8 Nitrite

Nitrite in solution was determined colorimetrically by the standard method (Ref. C-1). A reddish-purple dye was produced by the coupling of diazotized sulfanilic acid with naphthylamine hydrochloride. The dye was measured spectrophotometrically at 543 nm and compared to a standard calibration curve. A detection limit of 0.01 ppm was reported.

C.2.9 Sulfate

In aqueous samples, sulfate was determined by the addition of barium chloride (Ref. C-1). The resulting turbid solution was analyzed spectrophotometrically at 450 nm and compared to a standard calibration curve. A detection limit of 5 ppm was reported.

C.2.10 Sulfite - Sulfide

Total sulfite and sulfide in aqueous samples were analyzed by titrating a 25 ml aliquot with a standardized potassium iodide-iodine solution with starch as an end-point indicator (Ref. C-1).

C.2.11 pH

The pH of the aqueous samples was determined using a Corning Model 3D pH meter with a combination electrode.

C.2.12 Conductivity

The conductivity of the aqueous samples was determined using a YSI Model 33 conductivity meter.

C.2.13 Chemical Oxygen Demand (COD)

Chemical oxygen demand was determined by the standard method (Ref. C-1). Samples were refluxed for two hours with potassium dichromate and sulfuric acid. After cooling, the remaining dichromate was titrated with ferrous ammonium sulfate. The amount of potassium dichromate consumed was proportional to the amount of oxidizable organic matter in the sample. A detection limit of 5 ppm was reported.

C.2.14 Biochemical Oxygen Demand (BOD)

BOD was determined according to standard procedures (Ref. C-1). BOD is a measure of the change in dissolved oxygen after five days incubation at 20°C. An initial dissolved oxygen determination was made using the azide modification of the Winkler titration. In this procedure, iodine was liberated and titrated with a standard sodium thiosulfate solution. After five days a final concentration was determined. The change in dissolved oxygen was related to the amount of organic matter which was assimilated and oxidized by microorganisms.

C.2.15 Phenols

Phenols were analyzed in aqueous samples by standard methods (Ref. C-1). These methods include a distillation procedure in which phenols were removed from interferences and a colorimetric measurement. In the colorimetric procedure, phenols in the distillate were reacted with 4-aminoantipyrine at a pH of 10 in the presence of potassium ferricyanide to form a colored antipyrine dye. This dye was extracted with chloroform and the absorbance was measured spectrophotometrically at 460 nm. A detection limit of 10 ppb was reported.

C.2.16 Total Organic Carbon (TOC)

TOC was determined using a Dohrmann Model 54 TOC Analyzer. The sample was placed in a sparging reservoir and a potassium persulfate-phosphoric acid reagent was added. The inorganic carbon was purged from the sample, followed by UV oxidation of the organic carbon to CO_2. The CO_2 was subjected to reductive pyrolysis to produce methane. The total organic carbon content of the sample was determined using a flame ionization detector. A calibration curve was generated by analyzing known solutions of potassium acid phthalate. A detection limit of 10 ppb was reported.

C.3.0 ELEMENTAL ANALYSES

C.3.1 Spark Source Mass Spectrometry (SSMS)

Trace metals in the gas, liquid and solid streams were analyzed by spark source mass spectrometry. Gas samples were collected using two different sampling trains: the SASS silver persulfate method (Ref. C-5), and the acid/base collection method. The impinger volumes were determined and aliquots that represented a constant volume of gas were removed from each impinger in the sample train. These aliquots of absorbing solution were composited for SSMS analysis to form a representative sample from each sample train. Aliquots of the liquid and solid samples were sent directly for SSMS with no additional sample preparation. XAD-2 resin samples were combusted in an oxygen combustion bomb. The resulting gas was absorbed in dilute nitric acid and analyzed like the liquid samples.

C.3.2 Antimony, Arsenic, Selenium and Mercury

The volatile elements were analyzed directly from the composite impinger samples and aqueous samples by atomic absorption spectrophotometry (AAS). Solids were weighed into a Vycor cup and placed in a Parr combustion bomb. The bomb was sealed, pressurized with oxygen and the sample ignited. The resultant combustion products were absorbed in a 20% Ultrex nitric acid solution for analysis.

Arsenic, antimony, and selenium were analyzed using a hydride generation attachment for the atomic absorption spectrophotometer (Ref. C-5). An aliquot of sample was introduced into the system and acidified. Sodium borohydride was added to reduce the species to the hydride. The generated gas was purged into a hydrogen-argon flame for analysis.

The absorbances and detection limits for the hydride generation method are shown below:

Element	Wavelength	Detection Limit (ng/ml of solution)
As	193.7 nm	3 ppb
Sb	217.0 nm	5 ppb
Se	196.0 nm	4 ppb

Mercury was determined using the procedure of Hatch and Ott (Ref. C-6). Samples were acidified and the mercury oxidized with potassium permanganate. Hydroxylamine hydrochloride and stannous chloride were used to reduce the mercury to the metallic state. Then, air was bubbled through the solution. The mercury-entrained air was passed through the absorption cell of the spectrophotometer and quantified at 263.7 nm. A detection limit of 0.2 ppb was reported.

C.3.3 Inductively Coupled Argon Plasma Emission Spectrometry (ICPES)

Samples of ash pan water, service water, and perchloric acid digestions of gasifier ash, cyclone dust, and lignite were analyzed by ICPES. The liquid sample was aspirated into an argon plasma. The high temperature of the plasma (10,000°C) induces electronic excitation of the atoms. The emitted light was passed through a slit and diffracted by a grating. Photomultiplier tubes were set at the characteristic wavelengths of the elements measured.

C.3.4 Proximate/Ultimate Analysis

Proximate/ultimate analyses were done on solids by ASTM methods D-3172-73 and D-3176-74 (Ref C-7).

C.3.5 Gross Alpha and Beta Radiation

The amount of alpha and beta radiation emitted from the solid samples was measured by counting alpha and beta particles using a Geiger-Mueller tube. Differential absorbing plates were used to separate alpha particles from beta particles.

C.3.6 Specific Isotope Analyses

Samples of lignite, gasifier ash, and cyclone dust were analyzed for Radian by ORP/EERF. Each isotope emits a characteristic radiation. Therefore, various counting techniques were employed. Table C-1 lists the isotopes and the measurement technique.

C.4.0 ORGANIC ANALYSES

Preliminary analyses of the samples were done using established methods (Ref. C-5) with modifications. These modifications are included in the following descriptions of the analytical methods. Detailed analyses were done using a computer assisted gas chromatography - mass spectrometry system (GC-MS). GC-MS analysis was done after sample screening by gas chromatography (GC) using a selective detector in nitrogen-, sulfur- and halogen-specific modes. These GC analyses yielded data pertaining to organic compounds and compound classes which contain specific heteroatoms at very low additional cost to the comprehensive analysis.

TABLE C-1. ISOTOPE MEASUREMENT TECHNIQUE

Isotope	Detector
U-234	alpha spectrometry (surface barrier detector)
U-235	alpha spectrometry (surface barrier detector)
U-238	alpha spectrometry (surface barrier detector)
Th-227	alpha spectrometry (surface barrier detector)
Th-230	alpha spectrometry (surface barrier detector)
Th-232	alpha spectrometry (surface barrier detector)
Po-210	alpha spectrometry (surface barrier detector)
Pb-210	alpha-beta detector (IPC)
Ra-226	Lucas chamber
K-40	Ge-Li gamma spectrometer
Pb-214	Ge-Li gamma spectrometer
Bi-214	Ge-Li gamma spectrometer
Th-232 (ash)	Ge-Li gamma spectrometer

C.4.1 Extractions

Aliquots of the aqueous samples were extracted at both pH=2 and pH=12. Serial extractions using methylene chloride followed by diethyl ether were done at each pH to obtain a wider range of extractable organics than extraction with a single solvent would have yielded. After extraction, the methylene chloride and ether fractions were combined according to pH to yield 2 extracts for each sample. The extracts were concentrated using Kuderna-Danish concentrators equipped with 3-ball Snyder columns.

Aliquots of solid samples were extracted in Soxhlet extractors for 24 hours with methylene chloride followed by 24 hours with ether. After extraction, the 2 fractions were combined to yield one extract for each sample.

The use of diethyl ether to extract the aqueous and solid samples was an addition to the cited methods (Ref. C-5).

C.4.2 Total Chromatographable Organics Analysis (TCO)

TCO analysis is a means of quantitating organics with boiling points in the range of 100°C to 300°C using gas chromatography. Quantitation was performed by comparing sample chromatograms to an n-C_7-C_{17} + C_{20} boiling point standard and an n-C_8, C_{12}, C_{16} quantitative standard. The quantitative standard was analyzed at concentrations approximating sample concentrations. The following conditions were used:

Instrument:	Tracor Model 560 FID-GC
Column:	3.05 m x 2 mm ID glass, 10% OV-101 on 60/80 mesh Supelcoport
Carrier:	Helium at 40 ml/min

Injector: 265°C
Detector: 300°C
Oven Program: 50°C for 5 min: 20°C/min to 250°C; 250°C hold until baseline reestablished

Chromatograms were recorded and integrated with a Hewlett-Packard 3388 data system. Solvent blanks were analyzed for all samples and subtracted from sample values.

C.4.3 Gravimetric Analysis (GRAV)

GRAV analysis is a means of quantitating the non-volatile portion of a sample extract. Theoretically, this includes all compounds with a boiling point greater than 300°C. GRAV analyses were done on initial extracts and on liquid chromatographic (LC) fractions. A Mettler H-51 5-place analytical balance was used for all weighings.

GRAV analyses on the unfractionated extracts and LC fractions were done by taking volumetric aliquots of the concentrated extracts or LC fractions. The GRAV aliquots were placed in tared beakers and allowed to evaporate to dryness at room temperature in a dessicator. If less than 10 mg of material was present, additional aliquots were added until approximately 10 mg of GRAV material was present. In some cases for the LC fractions, this was not done due to low total masses in the fractions. Weighings were done at minimum 24-hour intervals until a maximum variation of ± 0.1 mg was observed. Solvent and LC fraction blanks were analyzed along with the samples and subtracted from sample values.

C.4.4 Gas Chromatographic Analysis -

Benzene, Toluene and Xylenes

Benzene, toluene and xylene samples were taken using 2-section glass tubes packed with activated charcoal. After sampling, the tubes were refrigerated until they could be extracted. Extraction was carried out by separate elution of the front and back charcoal aliquots with carbon disulfide for 30 minutes with shaking. Analyses of the front and back charcoal extracts were done separately using the following instrument parameters:

Instrument: Tracor Model 560 FID-GC
Column: 1.8 m x 2 mm ID glass, CP-5% SP-1200/1.75% Bentone 34 on 100/120 mesh Supelcoport
Carrier: Nitrogen at 20 ml/min
Injector Temperature: 275°C
Detector Temperature: 300°C
Oven Program: 75°C isothermal

Calibration was performed by injecting known quantities of benzene, toluene and the xylenes and establishing response factors for the compounds.

C.4.5 Liquid Chromatographic Separation (LC)

The LC separation gives a fractionation of the sample extract into compound classes based on polarity. This is not a high resolution technique and compound classes may overlap in individual fractions. However, with adequate care, reproducible, predictable separations can be achieved. Table C-2 presents the organic compound classes as separated into the seven LC fractions.

Samples were prepared for fractionation using recommended procedures (Ref. C-5). All extracts were solvent exchanged from methylene chloride/diethyl ether to cyclopentane over 200 mg silica gel using the recommended three 1 ml exchange evaporations. After the final concentration to 1 ml, the solvent exchange results in a solvent mixture containing less than 5% methylene chloride/ether. This is sufficiently low not to alter the polarity of the elution series. The exchanged extract and 200 mg silica gel were transferred to the LC column and eluted with a series of 7 solvent mixtures on the basis of increasing polarity. The LC column parameters were:

Column:	200 mm x 10.5 mm o.d., glass with Teflon stopcock, glass solvent reservoir; water jacketed, outlet water temperature 20°C
Absorbent:	Silica gel, 60-200 mesh, Davidson, Grade 950. Soxhlet extracted with methanol, methylene chloride and pentane, activated at 110°C for 2 hours. Slurry packed.
Drying Agent:	Sodium sulfate, reagent grade, fired at 500°C for 4 hours. 3 g added to top of column.
Elution Series:	pentane; methylene chloride/pentane 1:4; methylene chloride/pentane 1:1; methylene chloride; methanol/methylene chloride 1:4: methanol/methylene chloride 1:1. Pentane fraction = 25 ml, all others =10 ml.

C.4.6 Infrared Analyses

Infrared analyses were done using a Perkin-Elmer Model 283 grating spectrophotometer. The GRAV aliquots were taken up in methylene chloride and run as thin films between two sodium chloride plates. Absorbance spectra were run from 4000 cm^{-1} to 400 cm^{-1}. Daily quality checks were made to verity that the instrument met the operating requirements outlined (Ref. C-5).

C.4.7 Gas Chromatographic Analyses - Hall Detector

Gas chromatography was done using a Hall 700-A electrolytic conductivity detector (HECD). The HECD may be used in either the halogen, sulfur or nitrogen specific mode. Three analyses were performed on each extract, one in

TABLE C-2. COMPOUND CLASSES SEPARATION USING LIQUID CHROMATOGRAPHY TECHNIQUE+

Category (Subcategory)	Most probable LC fraction*	Category (Subcategory)	Most probable LC fraction*
Aliphatic hydrocarbons	1	Phenols	6
(Alkanes)	1	(Alkyl, etc.)	6
(Alkenes)	1	(Halogenated phenols)	6
(Alkynes)	1	(Nitrophenols)	6
Halogenated aliphatics	1,2	Esters	6
(Saturated)	1,2	(Phthalates)	6
(Unsaturated)	1,2	Ketones	6
Aromatic hydrocarbons	2,3	Amines	6
(Benzenes)	2,3	(Primary, secondary, tertiary)	6
Halogenated aromatic hydrocarbons	2,3	(Hydrazines, azo compounds)	6
Nitro aromatic hydrocarbons	4,5	(Nitrosoamines)	6
Fused alternate, nonalternate hydrocarbons	2,3	Heterocyclic nitrogen comopunds	
MW < 216 (methyl pyrene)	2,3	(Indoles, carbazoles)	4
MW > 216	2,3	(Quinolines, acridines)	6
Ethers	4	Aklyl sulfur compounds	6
(Halogenated ethers)	4	(Mercaptans)	6
Epoxides	4	(Sulfides, disulfides)	6
Aldehydes	4	Heterocyclic sulfur compounds	
Heterocyclic oxygen compounds	3,4 4	(Benzothiophenes)	4
Nitriles	4	Sulfonic acids, sulfoxides	7
(Aliphatic)	4	Amides	6
(Aromatic)	4		
Alcohols	6	Carboxylic acids	6,7
(Primary, secondary, tertiary)	6	Silicones	2,3,4
(Glycols)	6	Phosphates	5,6,7

*Possible assignments. Fractions 4-5, 5-6, 6-7 generally overlap to a considerable extent. Also, additional components of a particular molecule may cause it to elute in an LC fraction other than that expected. For example, a short-chain ester would probably elute in LC fraction 5 or 6 whereas a long-chain ester would elute in Fractions 3 or 4.

+Reference C-5.

each of the 3 detector modes. This provided measurements analogous to TCO values for classes of organic compounds containing specific heteroatoms. The analytical parameters were:

Instrument: Tracor Model 560 HECD-GC
Columns: 3.05 m x 2 mm ID glass, 10% OV-101 on 60/80 mesh Supelcoport (halogen and sulfur modes); 10% Apiezon L/2% KOH on 80/100 mesh Chromosorb W AW (nitrogen mode).
Carrier: Helium at 40 ml/min
Oven Program: 50°C for 5 min; 20°C/min to 250°C; 250°C hold until baseline reestablished.
Injector: Temperature: 265°C
Detector Temperature: 265°C
Block Standards: Halogen mode - chlorinated hydrocarbon
Sulfur mode - thiophene
Nitrogen mode - 2,4 dinitrotoluene

Samples were solvent exchanged with cyclopentane or methanol prior to analysis. Chromatograms were plotted and integrated with a Hewlett-Packard Model 3388 data processor. Standards were analyzed to provide boiling point references and concentration correlations. Solvent blanks were analyzed with the samples and subtracted from sample values.

C.4.8 Gas Chromatographic Analysis - RCRA Pesticides and Herbicides

Analyses of the Resource Conservation Recovery Act (RCRA) (Ref. C-8) pesticides were performed using a GC fitted with an electron capture detector (ECD). A 100 ml aliquot of the leachate was extracted serially with three 15 ml portions of hexane. The extract was concentrated to 10 ml using a Kuderna-Danish concentrator fitted with a 3-ball Snyder column.

A second 100 ml aliquot of the RCRA leachate was analyzed for herbicides. The sample was acidified to a pH of 1 and serially extracted with three 15 ml portions of diethyl ether. The extract was collected in a receiver containing 1 ml of 37% KOH and diluted with 15 ml distilled water. After heating for one hour, interfering organics were extracted with ether. The aqueous solution was acidified and the herbicides were extracted with ether. After methylation with diazomethane, the extract was concentrated for analysis. The instrument parameters were:

Instrument: Tracor Model 560 EC-GC
Column: 3.05 m x 2 mm ID glass, 1.5% SP-2250/1.95% SP-2401 on 100/120 mesh Supelcoport
Carrier: Nitrogen at 20 ml/min
Injector Temperature: 325°C

Detector
Temperature: 350°C
Oven Program: 205°C isothermal (pesticides); 160°C isothermal (herbicides)

C.4.9 Mass Spectrometric Analysis

Composited extracts for each of five samples were analyzed using gas chromatography - mass spectrometry (GC-MS). The samples were analyzed for the base-neutral and acid extractable EPA Priority Pollutants given in Table C-3 using a computer assisted search. This technique searches for specific compounds based on the appearance of 3 characteristic fragment ions within a known relative retention time window. Quantitation was done by response factor comparison to a known amount of d_{10}-anthracene used as an internal standard.

In addition to priority pollutant analysis, the major non-priority pollutant peaks were identified in each sample spectrum. These peaks along with the unidentified mass in each spectrum were quantified assuming a response factor of 1.0 relative to d_{10}-anthracene.

Samples were analyzed by GC-MS using the following parameters:

Instrument: Hewlett-Packard 5985 GC-MS system;
Columns: 1.8 m x 2 mm ID glass; 3% SP-2250 DB on 100/120 mesh Supelcoport (base-neutrals); 1% SP-1240 DA on 100/120 mesh Supelcoport (acids).
Carrier: Helium at 30 ml/min.

Oven
Program: 50°C for 4 min, 8°C/min to 260°C, 260°C for 20 min (base-neutrals); 70°C for 1 min, 10°C/min to 200°C, 200°C for 15 min (acids).
Ionization
Voltage: 70 eV

C.5.0 LEACHING STUDIES

Gasifier ash and cyclone dust were extracted using the Resource Conservation and Recovery Act (RCRA) procedure as outlined in the Federal Register of December 18, 1978, 'Hazardous Waste, Proposed guidelines and Regulations' (Ref. C-8). One hundred grams of the air dried solid was weighed into a polyethylene bottle along with a weight of deionized water equal to 16 times the weight of the solid. The pH was adjusted to 5.0 with Ultrex glacial acetic acid. The pH was monitored for one hour and adjusted as needed.

The sample was agitated for 24 hours with a rotary shaker. At the end of the 24-hour leaching, the samples were filtered through a 0.45 micron Millipore filter. The filtrate was diluted to 20 times the initial weight of the solid. The dilute filtrates and blanks were preserved for analysis.

TABLE C-3. BASE-NEUTRAL AND ACID EXTRACTABLE PRIORITY POLLUTANTS ANALYZED BY GC-MS

Base-Neutral Extractable			Acid Extractable		
	Compound	m/e		Compound	m/e
1.	1,3-Dichlorobenzene	146	1.	2-Chlorophenol	128
2.	1,4-Dichlorobenzene	146	2.	2-Nitrophenol	139
3.	Hexachloroethane	117	3.	Phenol	94
4.	1,2-Dichlorobenzene	146	4.	2,4-Dimethylphenol	122
5.	Bis(2-Chloroethyl) ether	93	5.	2,4-Dichlorophenol	162
6.	Bis(2-Chloroisopropyl) ether	121	6.	2,4,6-Trichlorophenol	196
7.	Nitrobenzene	77	7.	p-Chloro-m-cresol	142
8.	N-Nitrosodimethylamine	74	8.	2,4-Dinitrophenol	184
9.	N-Nitrosodi-n-propylamine		9.	4,6-Dinitro-o-cresol	198
10.	Hexachlorobutadiene	225	10.	Pentachlorophenol	266
11.	Isophorone	82	11.	4-Nitrophenol	139
12.	1,2,4-Trichlorobenzene	180	12.	2,2-Difluorobiphenyl	190
13.	Bis(2-Chloroethoxy) methane	93			
14.	Naphthalene	128			
15.	Hexachlorocyclopentadiene	237			
16.	2-Chloronaphthalene	162			
17.	Acenaphthylene	152			
18.	Acenaphthene	154			
19.	Dimethyl phthalate	163			
20.	2,6-Dinitrotoluene	63			
21.	4-Chlorophenyl phenyl ether	204			
22.	Fluorene	166			
23.	2,4-Dinitrotoluene	63			
24.	Diethyl phthalate	149			
25.	N-Nitrosodiphenylamine	169			
26.	1,2-Diphenyl Hydrazine	77			
27.	Hexachlorobenzene	284			
28.	4-Bromophenyl phenyl ether	248			
29.	Phenanthrene	178			
30.	Anthracene	178			
31.	Di-n-butyl phthalate	149			
32.	Fluoranthene	202			
33.	Pyrene	202			
34.	Benzidine	184			
35.	Butyl benzyl phthalate	149			

(Continued)

TABLE C-3. Continued

Base-Neutral Extractable			Acid Extractable	
	Compound	m/e	Compound	m/e
36.	Bis(2-Ethylhexyl) phthalate	149		
37.	ICDD	322		
38.	Chrysene	228		
39.	Benz(a)anthracene	228		
40.	3,3-Dichlorobenzidine	252		
41.	Di-n-octyl phthalate	149		
42.	Benzo(b)fluoranthene	252		
43.	Benzo(k)fluoranthene	252		
44.	Benzo(a)pyrene	252		
45.	Indeno (1,2,3-c,d)pyrene	276		
46.	Benzo(a,h)anthracene	278		
47.	Benzo(g,h,i)perylene	276		

In addition to the RCRA leachate, neutral leachates for the ash and dust were prepared. The RCRA extraction procedure was used with the exception that no pH buffer was added to the leaching solution.

The leachates were analyzed for water quality parameters and elemental composition using the procedures in Sections C.1.0 and C.2.0 respectively. Pesticide and herbicide analyses were carried out on the RCRA leachates using the procedures in Section C.4.0. In addition, bioassay testing was performed on the neutral leachates by Arthur D. Little, Inc.

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APPENDIX D

PRODUCT GAS MONITORING FOR SULFUR SPECIES, HYDROCARBONS AND MAJOR GASES USING PROCESS GAS CHROMATOGRAPHS

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D.1.0 INTRODUCTION

This appendix describes the methods used by Radian Corporation for the continuous monitoring of product gas by process gas chromatographs during the Riley Gas Producer demonstration run. Radian measured sulfur species, hydrocarbons, and major gases. Due to the presence of tars and oils in the product gas, aerosol material was removed from the sample stream using an electrostatic precipitator. The product gas sampling location is shown in Figure D-1.

D.2.0 ANALYTICAL APPROACH

Radian monitored the product gas continuously with an on-line gas chromatographic system. The system consisted of three process gas chromatographs: the first with a flame photometric detector (FPD) for sulfur species, the second with a flame ionization detector (FID) for hydrocarbons, and the third with a thermal conductivity detector (TCD) for major gases.

A single sample acquisition and gas conditioning system delivered sample gas to the three gas chromatographs, which operated independently. Electronically controlled valves delivered a portion of the sample gas into individual analyzers upon command from a control panel. Each analyzer was equipped with a sample loop/valve injection system through which the sample was continuously purged. The control panel then directed the analyzer through the analytical program. Outputs of the instruments were recorded on strip chart recorders. The sample injection/analytical program sequence varied from six to ten minutes, depending on the instrument.

Standard gases of the components being analyzed were injected into the gas chromatographs before and after the analytical period. Concentrations of product gas components were determined by comparison of peak heights of the product gas to peak heights of the standard gases.

D.2.1 Sulfur Species

The sulfur species measured were H_2S and COS. Although the system was capable of measuring CS_2 and SO_2, they were not detected.

The analyses were performed with either an Applied Automation Model 7770 process gas chromatograph or a Bendix Model 7000 process gas chromatograph. Each chromatograph was equipped with a flame photometric detector. The conditions for the analyses are listed below:

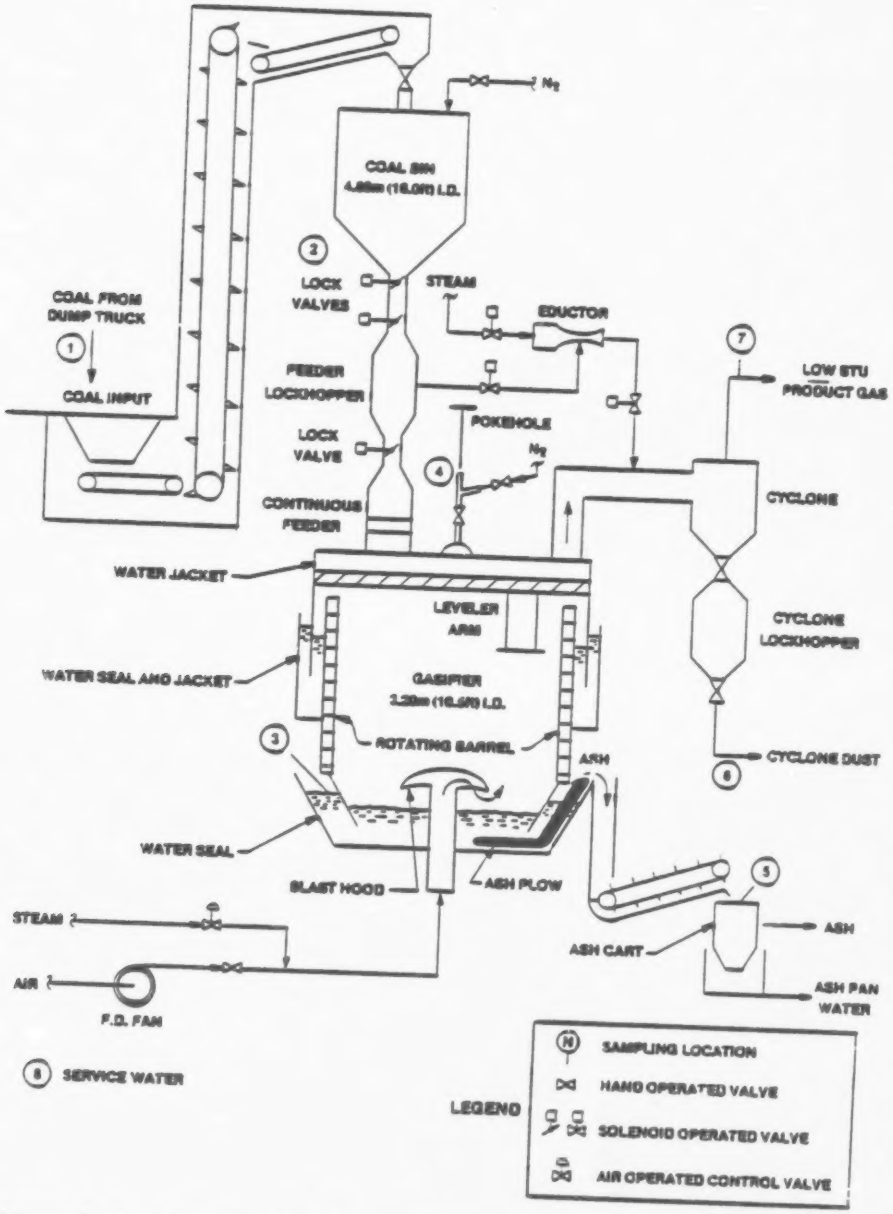
N₂
COAL BIN
4.88m (16.0ft) I.D.
②
LOCK VALVES
STEAM
EDUCTOR
COAL FROM DUMP TRUCK
①
COAL INPUT
⑦
LOW BTU PRODUCT GAS
FEEDER LOCKHOPPER
POKEHOLE
LOCK VALVE
④
N₂
CONTINUOUS FEEDER
CYCLONE
WATER JACKET
LEVELER ARM
CYCLONE LOCKHOPPER
WATER SEAL AND JACKET
GASIFIER
3.20m (10.5ft) I.D.
③
ROTATING BARREL
ASH
CYCLONE DUST
⑥
WATER SEAL
BLAST HOOD
ASH PLOW
⑤
STEAM
ASH
ASH CART
AIR
F.D. FAN
ASH PAN WATER
⑧ SERVICE WATER
LEGEND
Ⓝ SAMPLING LOCATION
HAND OPERATED VALVE
SOLENOID OPERATED VALVE
AIR OPERATED CONTROL VALVE

Figure D-1. Schematic of the Riley-Morgan Gasifier Showing Process GC's Sampling Location

Applied Automation:

Carrier:	Nitrogen
Flow:	Column, 45 ml/min; Backflush, 45 ml/min
Oven and Detector Temperature:	107°C
Columns:	0.3 m x 3.2 mm Teflon, 40% Carbowax on 80/100 Chromosorb P; 3.7 m x 3.2 mm Stainless Steel, 1% TCEP on 80.100 Porasil B
Sample Size and Operation Time:	70 µl, 6 min
Detection Limits:	H_2S, ~10 ppm COS, ~10 ppm

Bendix:

Carrier:	Air
Flow:	Column, 60 ml/min, Backflush, 65 ml/min
Oven and Detector Temperature:	81°C
Columns:	0.9 m x 3.2 mm Stainless Steel, BSG (Bendix Sulfur Gas Packing); 1.8 m x 3.2 mm Stainless Steel, Porapak Q; 0.6 m x 3.2 mm Stainless Steel, BSG
Sample Size and Operation Time:	20 µl, 480 min

The calibration curves for COS and H_2S are given in Figures D-2 and D-3, respectively.

D.2.2 Hydrocarbons

The hydrocarbons measured were methane, ethane, ethylene, propane, and butane and larger as a composite. The hydrocarbon species were compared to standard gases of like compounds, except that the butane and larger (C_4+) composite was compared to a butane standard only. Therefore, the C_4^+ values presented are as butane.

The analyses were performed with either an Applied Automation Model 7270 process gas chromatograph or a Bendix Model 7000 process gas chromatograph. Each instrument was equipped with a flame ionization detector. The conditions for the analyses are listed below.

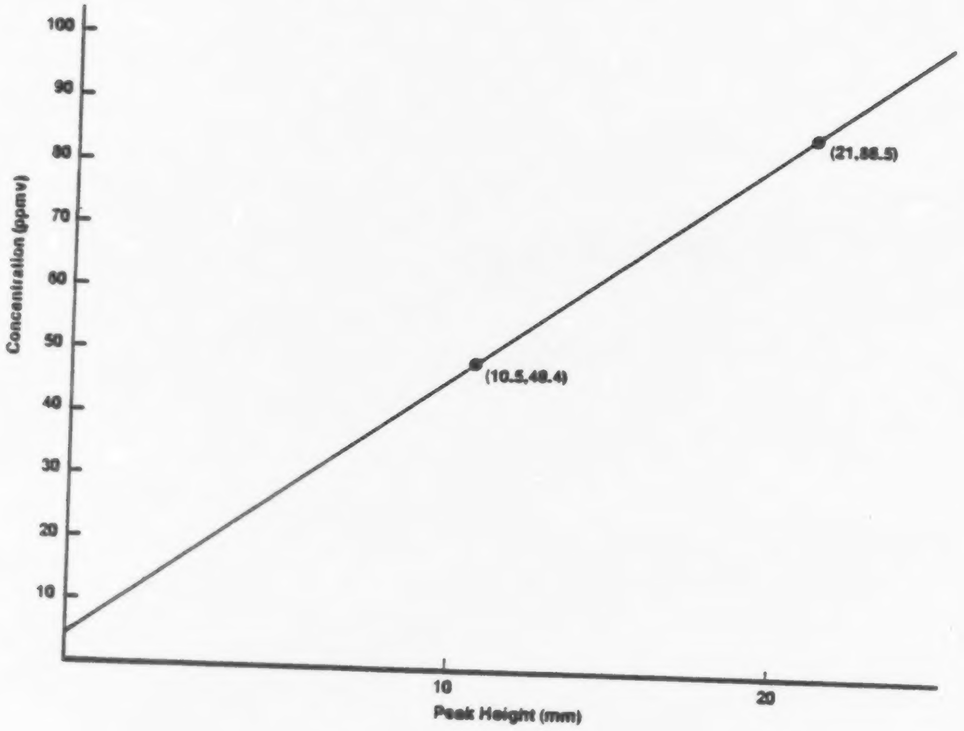

Figure D-2. COS Calibration Curve

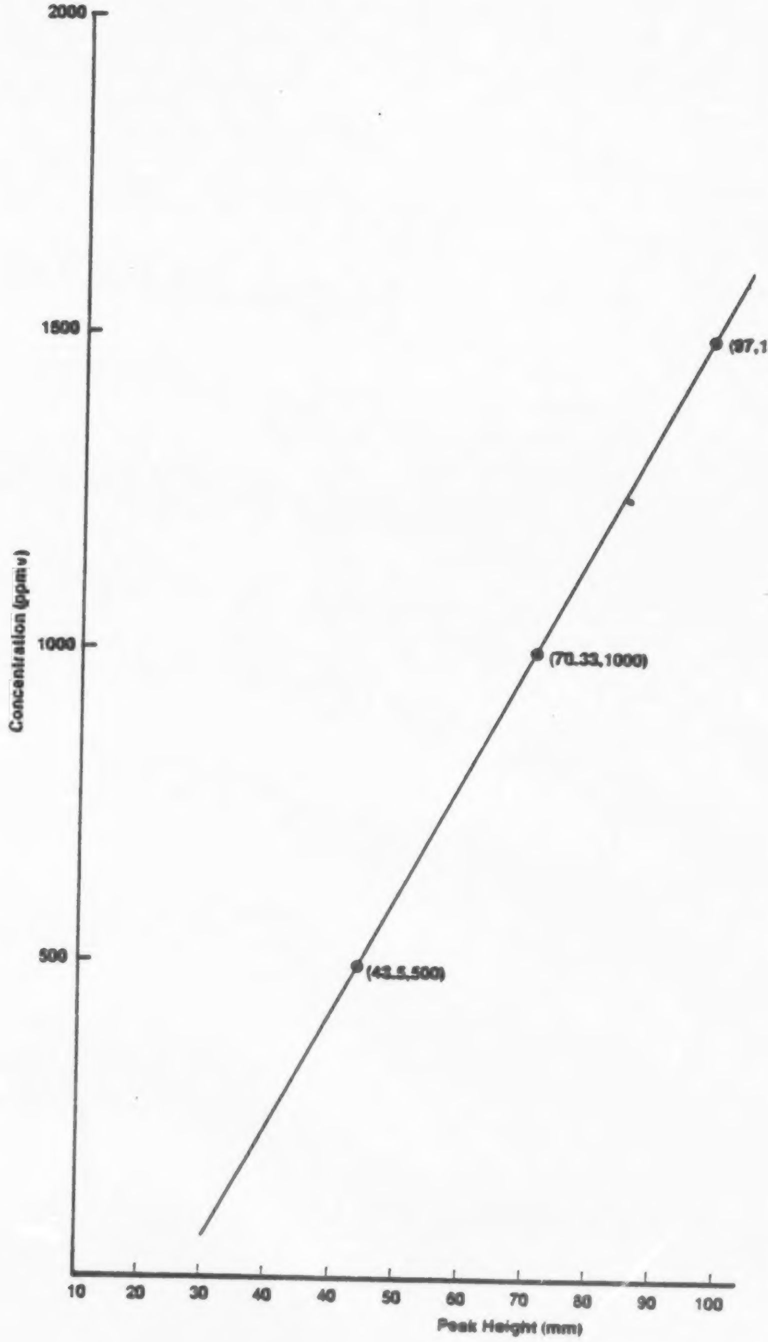

Figure D-3. H_2S Calibration Curve

Applied Automation:

Carrier:	Nitrogen
Flows:	Column, 30 ml/min; Backflush, 30 ml/min
Oven and Detector Temperature:	141°C
Columns:	0.6 m x 3.2 mm Stainless Steel, Porapak T, 80/100; 4.3 m x 3.2 mm Stainless Steel, Porasil A, 80/100; 0.3 m x 32 mm Stainless Steel, Chromasorb G, 80/100
Sample Size and Operation Time:	170 µl, 8 1/2 min
Detection Limits:	Methane, ~50 ppm Ethane, ~50 ppm Ethylene, ~100 ppm Propane, ~50 ppm C_4^+, ~100 ppm

Bendix:

Carrier:	Nitrogen
Flows:	Column, 45 ml/min, Backflush, 55 ml/min
Oven and Detector Temperature:	70°C
Columns:	0.9 m x 3.2 mm Stainless Steel, Porapak Q; 1.8 m x 3.2 mm Stainless Steel, OPN on Porasil C; 0.6 m x 3.2 mm Stainless Steel, OPN on Porasil C
Sample Size and Operation Time:	20 µl, 300 min

Figures D-4 through D-8 present the calibration curves for the hydrocarbon analyses.

D.2.3 Major Gases

The major gases measured were H_2, O_2+Ar, N_2, CO_2 and CO. The analyses were performed with either an Applied Automation Model 7170 process gas chromatograph or a Bendix Model 7000 process gas chromatograph. Each instrument was equipped with a thermal conductivity detector. The conditions for the analyses are listed below.

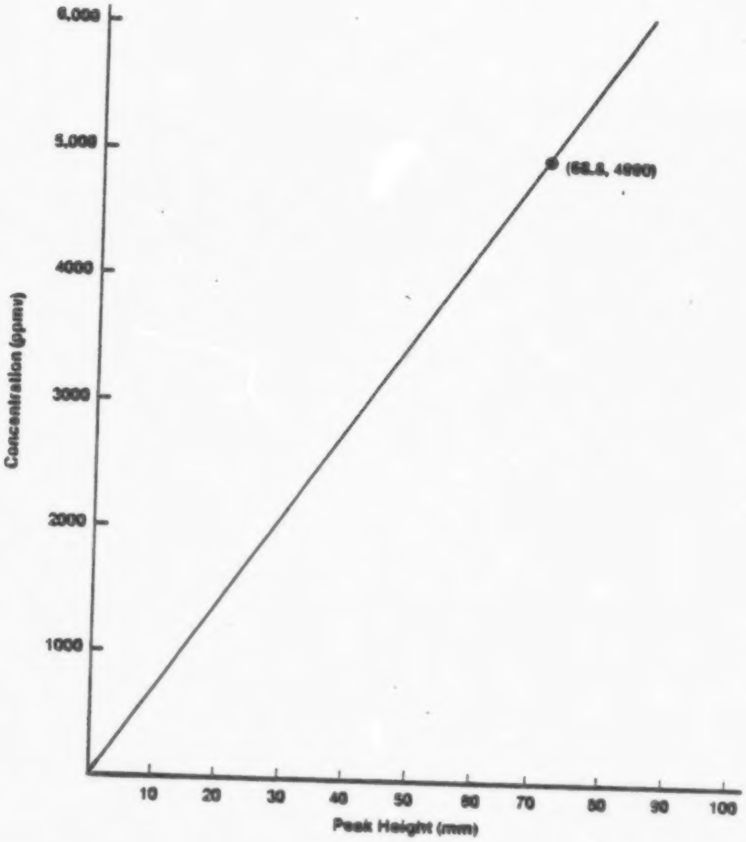

Figure D-4. Methane Calibration Curve

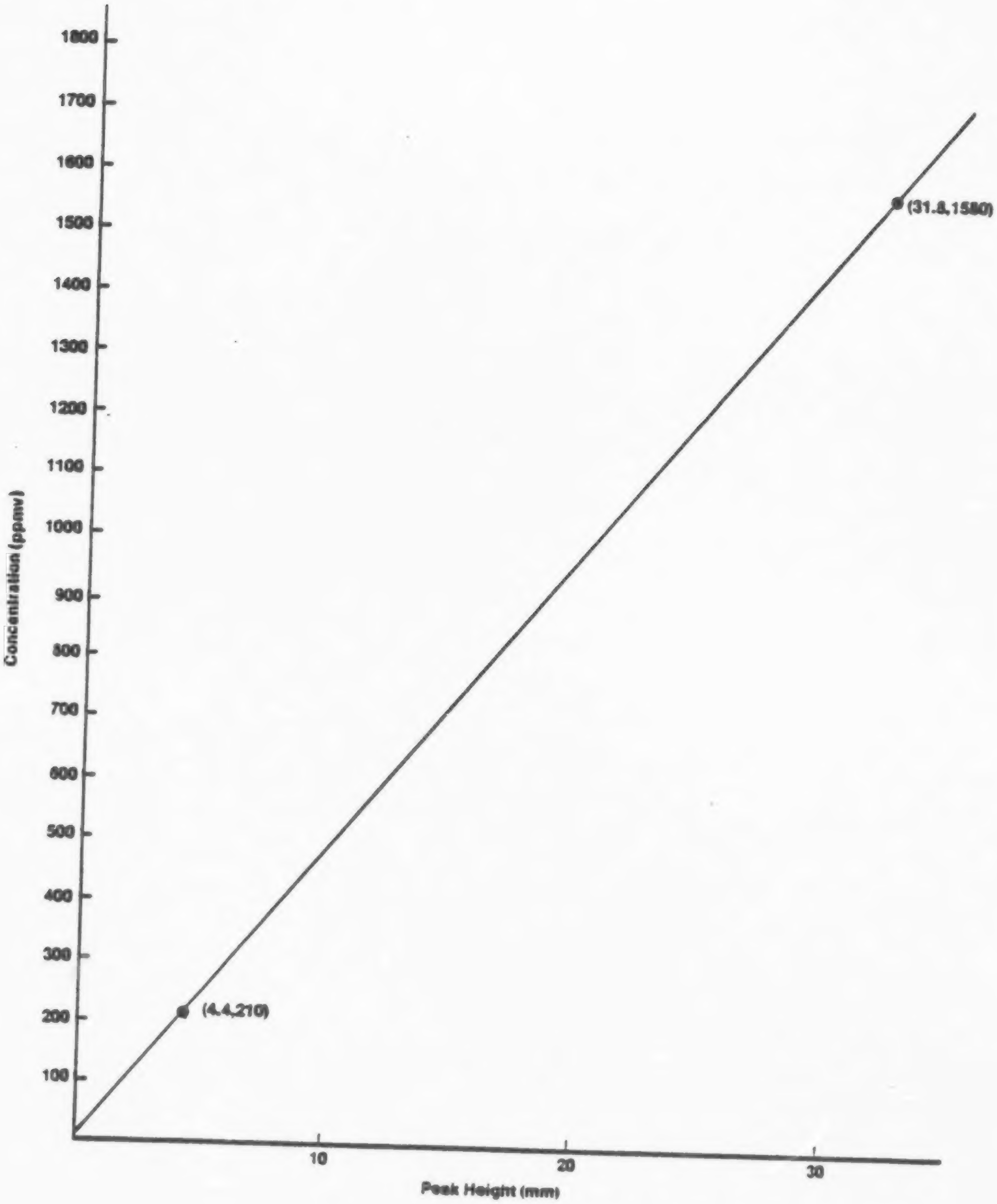

Figure D-5. Ethane Calibration Curve

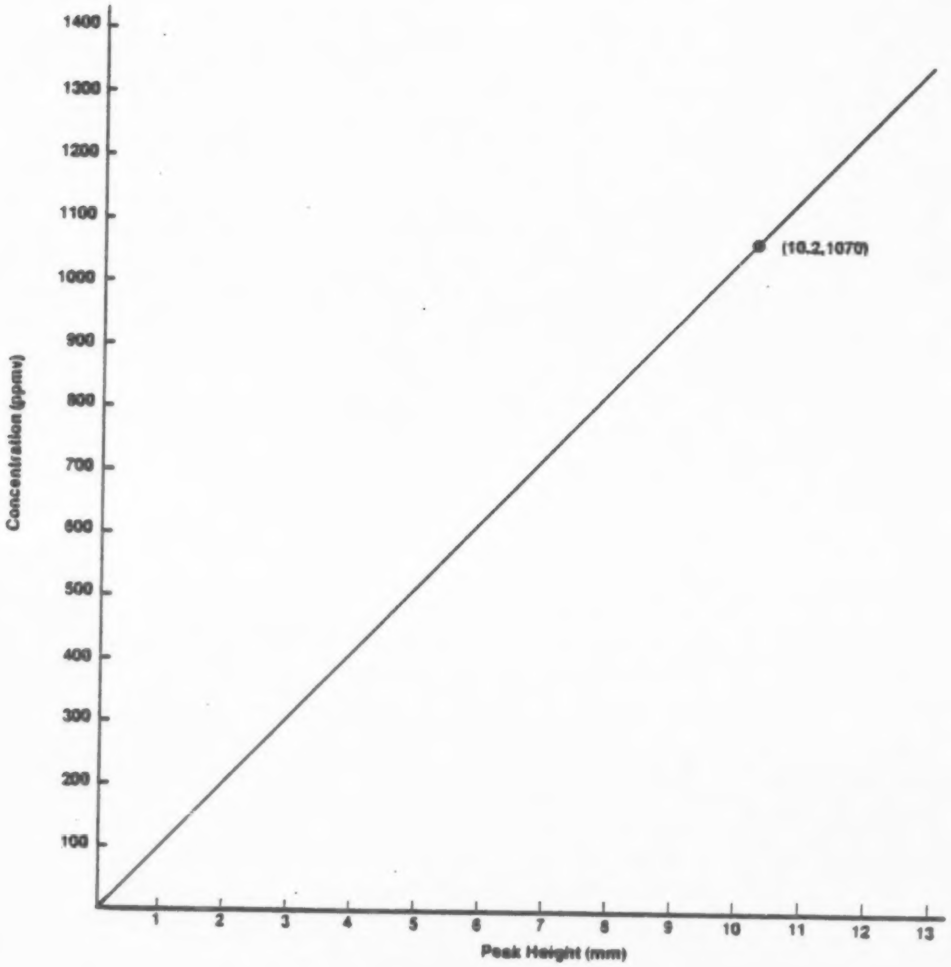

Figure D-6. Ethylene Calibration Curve

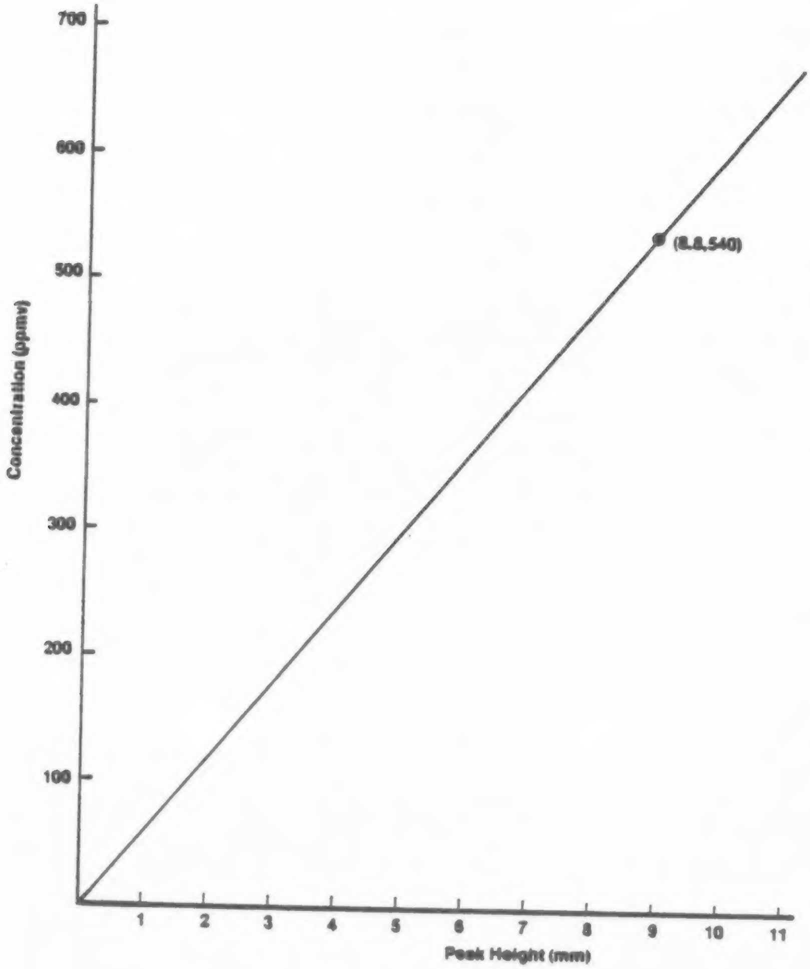

Figure D-7. Propane Calibration Curve

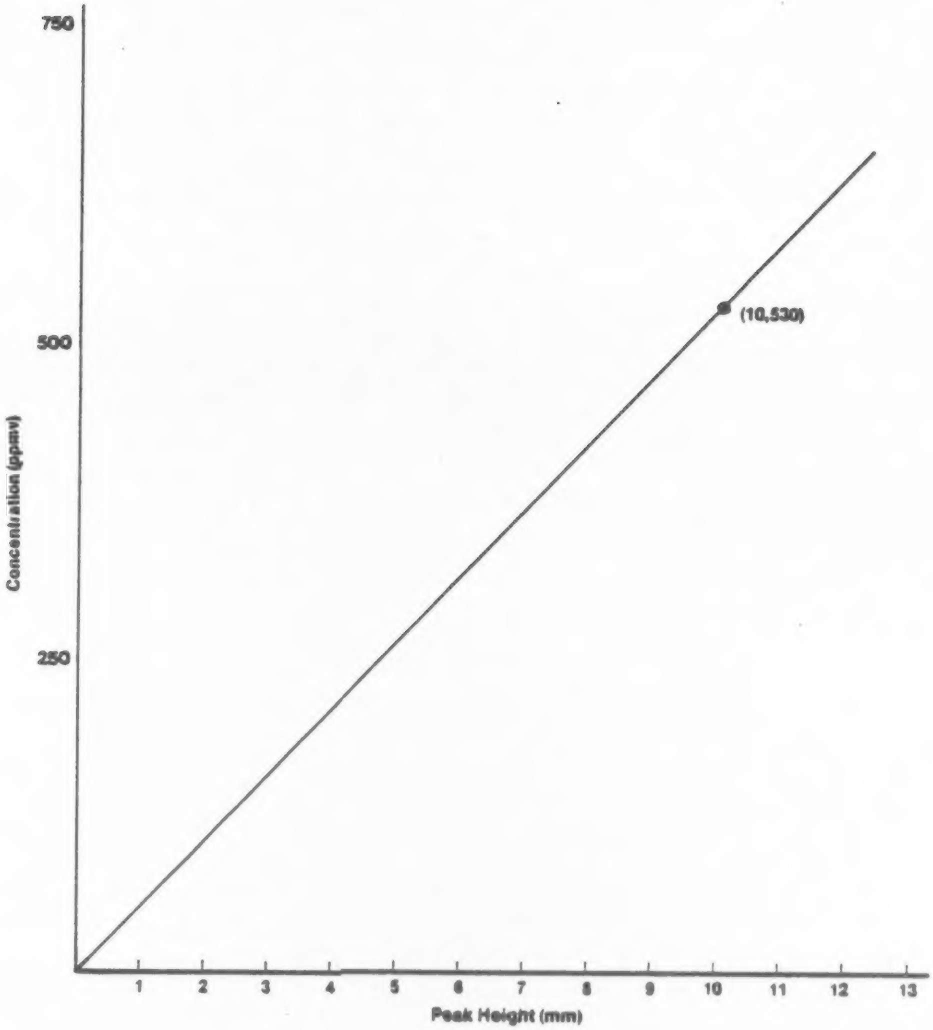

Figure D-8. C_4+ (as Butane) Calibration Curve

Applied Automation:

Carrier:	8.5% Hydrogen in Helium
Flows:	Column, 30 ml/min, Reference, 30 ml/min; Backflush, 50 ml/min
Oven and Detector Temperature:	285°C
Columns:	4.0 m x 3.2 mm Stainless Steel, Porapak Q; 3.0 m x 3.2 mm Stainless Steel, Molecular Sieve SA
Sample Size and Operation Time:	10 cc, 10 min 15 sec
Detection Limits:	H_2, ~3% O_2, ~0.3% N_2, ~0.1% CO_2, ~0.1% CO, ~1%

Bendix:

Carrier:	8.5% Hydrogen in Helium
Flows:	Column, 45 ml/min; Reference, 30 ml/min; Backflush, 60 ml/min
Oven and Detector Temperature:	60°C
Columns:	2.4 m x 3.2 mm Stainless Steel, Porapak Q; 1.5 m x 3.2 mm Stainless Steel, Porapak Q; 2.4 m x 3.2 mm Stainless Steel, Molecular Sieve SA
Sample Size and Operation Time:	5 cc, 310 min

Figures D-9 through D-13 present the calibration curves for the analyses of major gases.

D.3.0 SAMPLING SYSTEM

A pump capable of drawing 0.25 cubic feet per minute was used to draw a sample of the product gas through a clean-up system. A large amount of sample was drawn in order to minimize residence time in the sampling system. A second pump drew a portion of the main sample stream and delivered it to the analyzers. Figure D-14 shows a diagram of the sampling and analytical system.

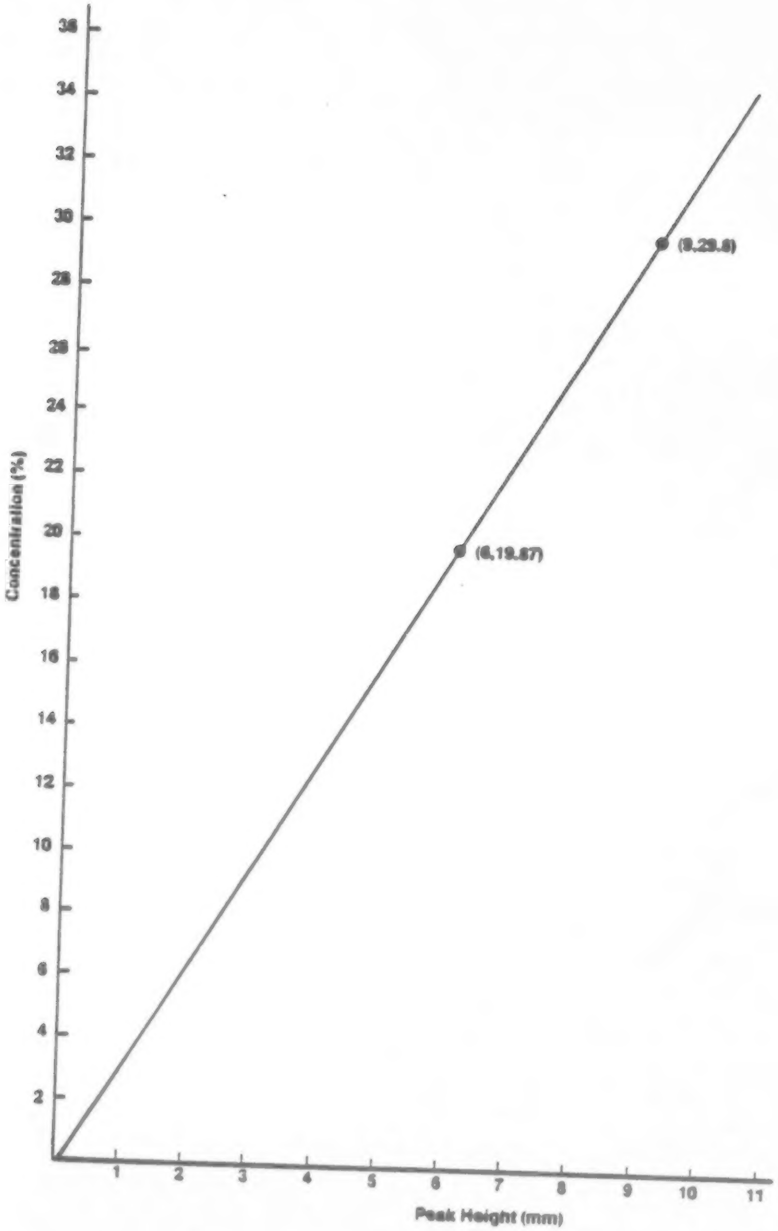

Figure D-9. H_2 Calibration Curve

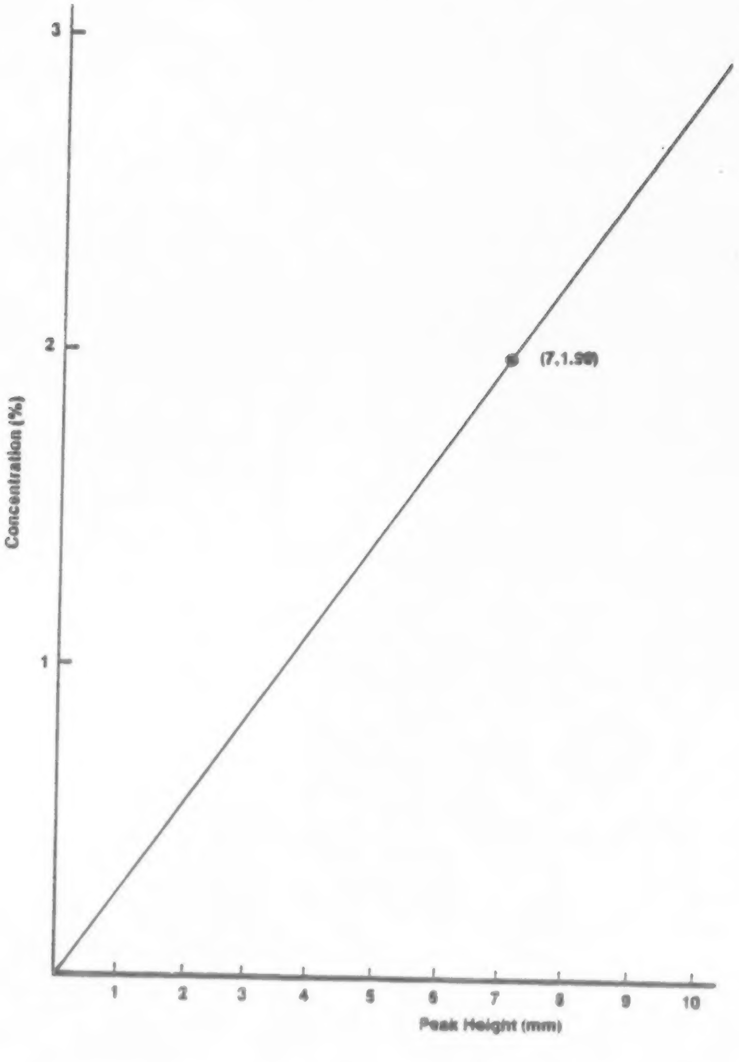

Figure D-10. O_2 Calibration Curve

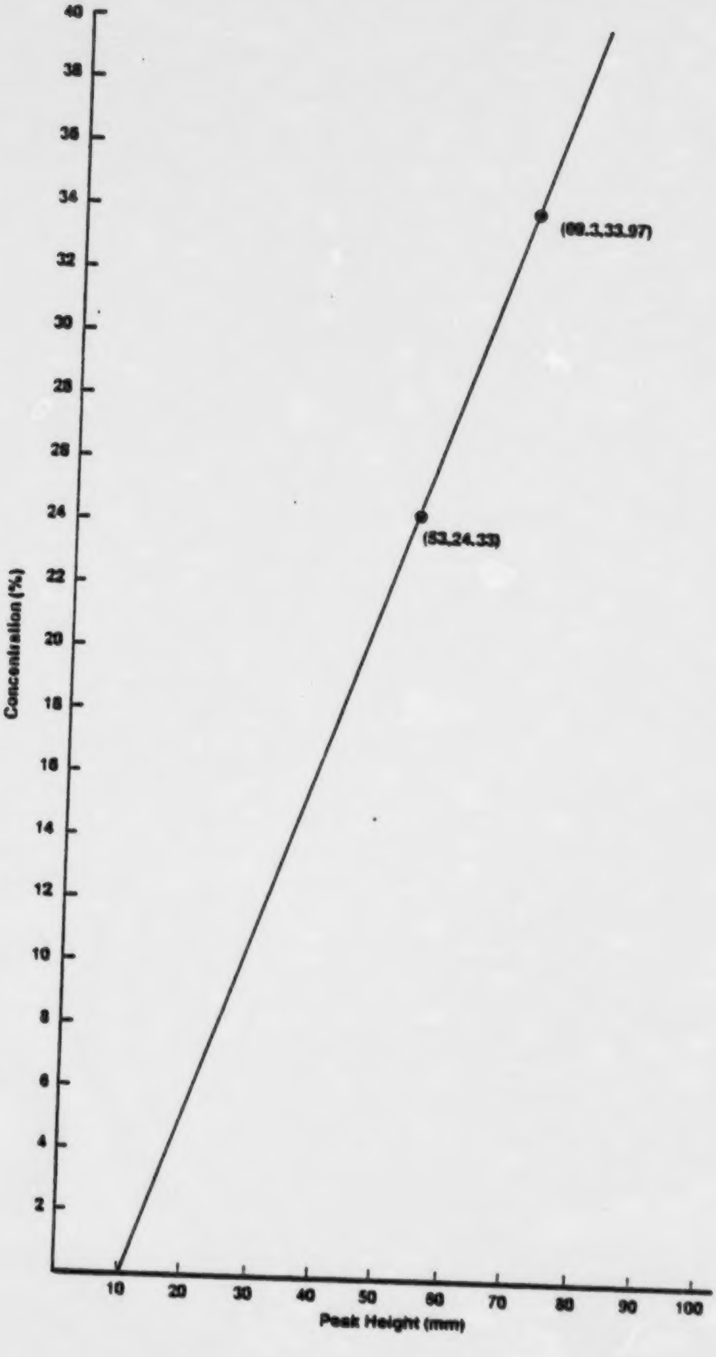

Figure D-11. N_2 Calibration Curve

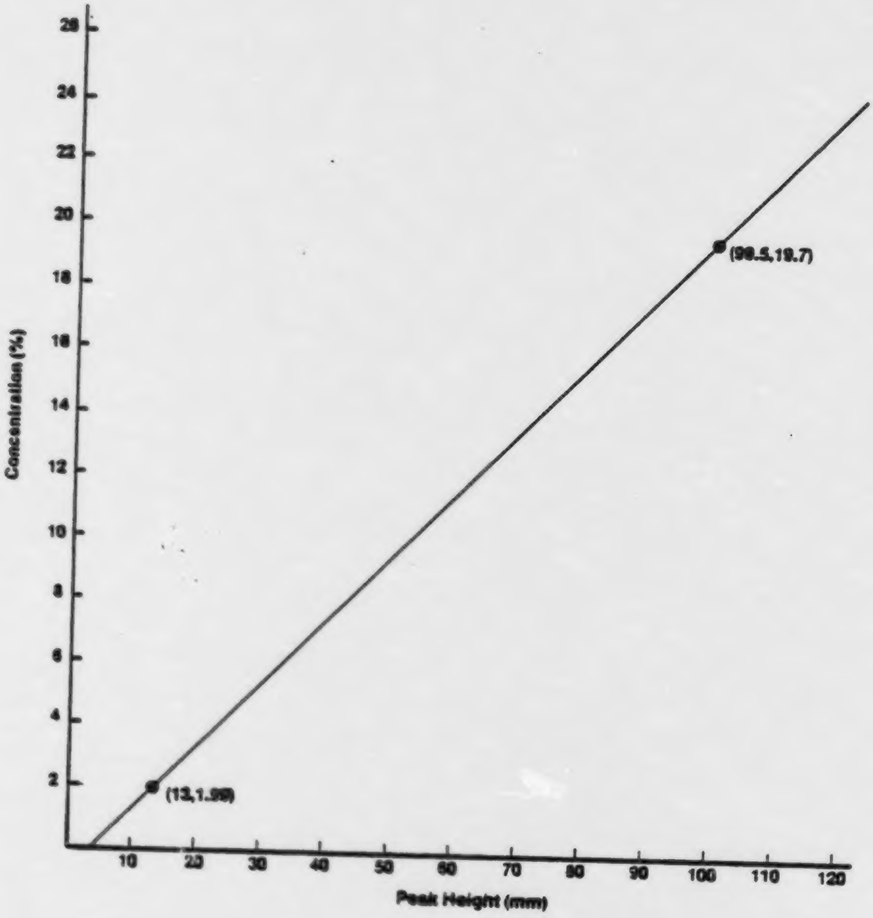

Figure D-12. CO_2 Calibration Curve

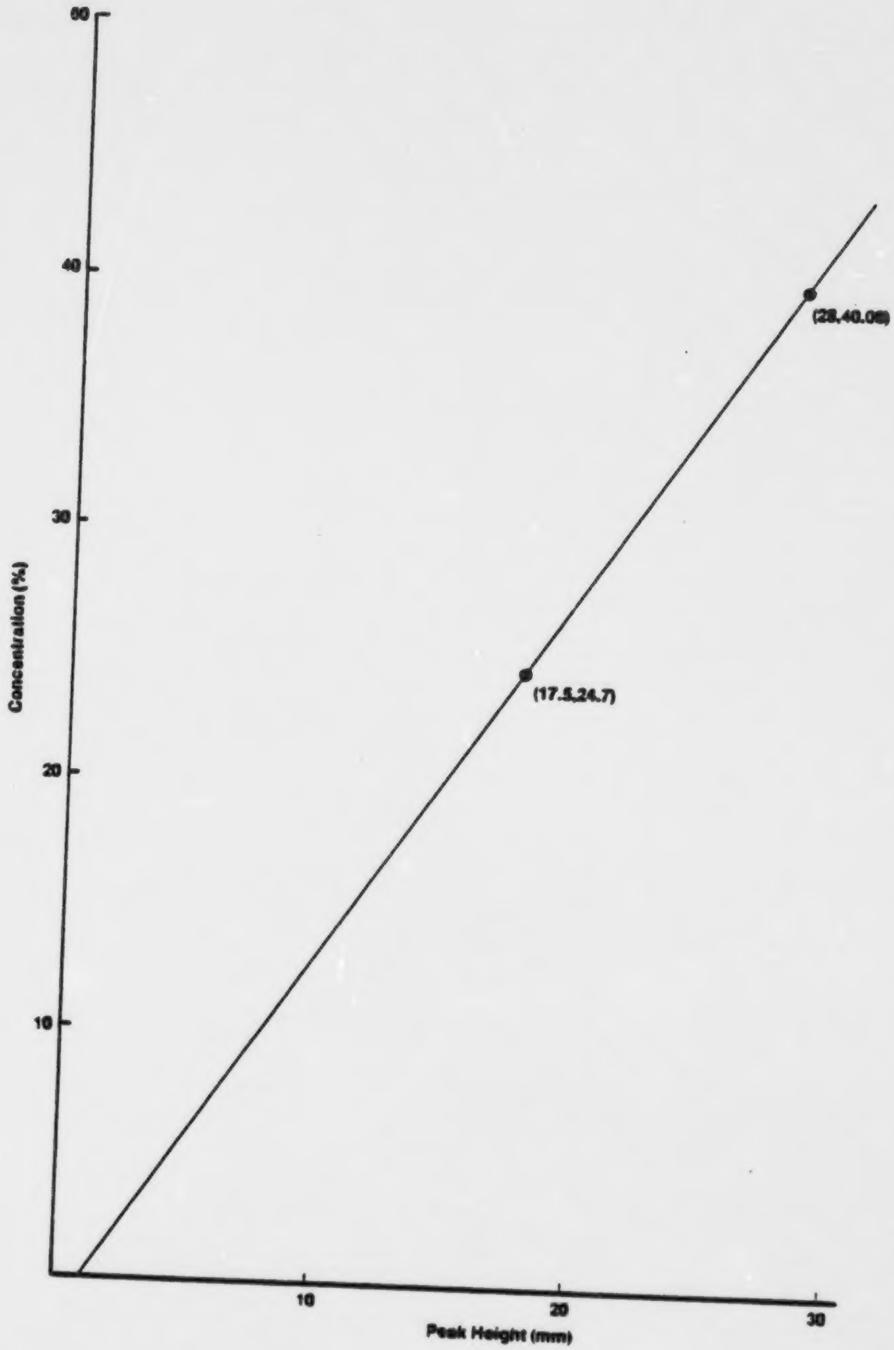

Figure D-13. CO Calibration Curve

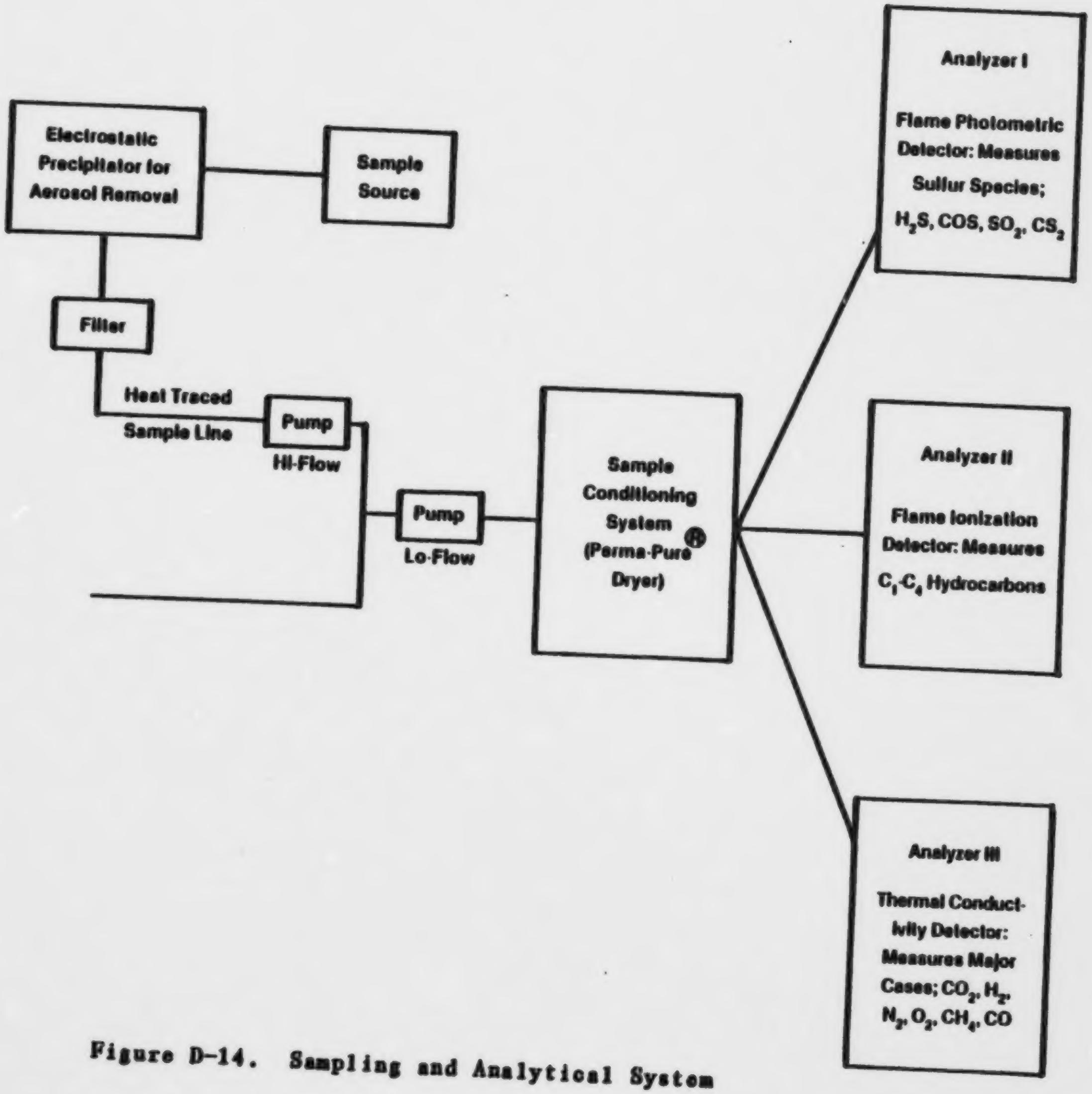
Electrostatic Precipitator for Aerosol Removal
Sample Source
Filter
Heat Traced Sample Line
Pump
Hi-Flow
Pump
Lo-Flow
Sample Conditioning System (Perma-Pure® Dryer)
Analyzer I
Flame Photometric Detector: Measures Sulfur Species; H_2S, COS, SO_2, CS_2
Analyzer II
Flame Ionization Detector: Measures C_1-C_4 Hydrocarbons
Analyzer III
Thermal Conductivity Detector: Measures Major Cases; CO_2, H_2, N_2, O_2, CH_4, CO

Figure D-14. Sampling and Analytical System

A 1/2-inch stainless steel probe was inserted directly into the product gas stream. The probe was attached to the an electrostatic precipitator (ESP), which removed particulates, tars and oils. The ESP was operated at 70°C (160°F) and a voltage of 12 kv.

A glass fiber filter was located directly behind the ESP to further reduce the amount of particulates in the sample stream. The sample gas stream then passed through a heat-traced Teflon line to the shelter housing the analyzers.

A portion of the sample gas stream was continuously pumped to the sample conditioning system while the main sample gas stream was vented. The sample conditioning system was a heating enclosure containing an osmotic dryer (Perma-Pure) to remove water from the gas and a series of valves to deliver a sample of the gas to each of the analyzers. Each analyzer was equipped with a sample loop-valve injection system through which sample was continuously purged.

D.4.0 ANALYTICAL RESULTS

The product gas was analyzed continuously for sulfur species, hydrocarbons, and major gases during the following time periods:

Sulfur	12/13:	1502-2213
		2343-0142 (12/14)
	12/14:	0342-0504
Hydrocarbons	12/13:	1146-1311
		1441-2041
		2171-0636 (12/14)
Major Gases:	12/13:	1434-1824
		1954-1349 (12/14)

Tables D-1, D-2, and D-3 present the analytical results obtained for sulfur species, hydrocarbons, and major gases, respectively. All results in the tables are on a dry gas basis. Table D-4 shows the average gas compositions determined by process gas chromatographs.

TABLE D-1. PRODUCT GAS SULFUR SPECIES CONCENTRATIONS

DATE	TIME	COS(ppmv)	H_2S(ppmv)	DATE	TIME	COS(ppmv)	H_2S(ppmv)
12/13/79	1502	135	1060	12/13/79	1733	125	1360
	1508	130	1040		1739	120	1370
	1514	145	850		1745	120	1390
	1520	150	880		1751	115	1390
	1526	120	1210		1758	120	1410
	1532	110	1150		1804	120	1430
	1538	110	1270		1810	120	1420
	1544	110	1280		1816	125	1410
	1550	110	1250		1822	120	1430
	1556	120	1280		1828	125	1350
	1602	110	1240		1834	120	1350
	1608	110	1260		1840	145	1200
	1614	110	1240		1846	125	1320
	1620	110	1260		1852	130	1360
	1626	115	1280		1858	160	1500
	1632	110	1270		1904	165	1280
	1638	120	1280		1910	145	1410
	1645	115	1300		1916	165	1050
	1651	120	1330		1922	140	1330
	1657	110	1330		1930	165	1000
	1703	120	1380		1933	130	1340
	1709	120	1420		1940	120	1290
	1715	120	1390		1947	120	1280
	1721	120	1350		1953	120	1270
	1727	115	1360		1959	120	1210

(Continued)

TABLE D-1. Continued

DATE	TIME	COS(ppmv)	H_2S(ppmv)	DATE	TIME	COS(ppmv)	H_2S(ppmv)
12/13/79	2005	125	1230	12/14/79	0015	115	1130
	2011	130	1180		0021	120	1280
	2017	125	1160		0028	120	1260
	2023	135	1020		0045	110	1000
	2029	135	1110		0052	110	1030
	2035	130	990		0059	135	990
	2041	135	1120		0106	105	950
	2047	140	1090		0115	110	1090
	2053	140	1140		0135	105	360
	2059	130	1220		0142	105	420
	2105	130	1290		0339	90	680
	2111	115	1310		0348	90	550
	2117	130	1280		0356	90	620
	2121	135	1110		0405	90	360
	2127	135	1090		0416	90	390
	2133	145	1020		0431	95	270
	2139	130	1210		0435	100	360
	2145	120	1200		0441	100	450
	2151	110	1270		0447	100	450
	2159	125	1300		0454	100	540
	2211	120	1360		0504	95	350
	2213	125	1320		0519	100	230
	2336	115	1090		0537	95	570
					0546	90	380

TABLE D-2. PRODUCT GAS HYDROCARBONS CONCENTRATIONS

DATE	TIME	C_4+ (as butane) (ppmv)	METHANE (ppmv)	ETHANE (ppmv)	ETHYLENE (ppmv)	PROPANE (ppmv)
12/13/79	1146	210	5600	320	160	200
	1154	240	5350	320	210	200
	1202	290	8180	440	210	240
	1210	240	5600	340	–	–
	1215	240	6180	340	210	200
	1233	240	6040	340	210	200
	1240	260	6330	340	210	200
	1247	320	8980	460	260	240
	1253	320	8870	460	260	240
	1300	320	9380	490	210	270
	1306	320	8910	440	–	–
	1311	240	7060	390	370	–
	1424	260	–	440	190	160
	1443	330	–	460	260	140
	1451	320	–	470	250	180
	1503	260	6400	320	210	200
	1511	260	7200	340	260	170
	1519	290	7750	340	320	170
	1527	260	6840	340	260	170
	1535	450	14000	660	420	270
	1543	480	14200	690	420	300
	1551	290	7780	420	260	200
	1559	260	6840	340	210	170
	1607	340	10000	520	260	240
	1615	400	12500	620	320	270
	1623	260	7350	360	210	200
	1631	370	10500	520	260	240
	1639	480	14400	690	370	270

(Continued)

TABLE D-2. Continued

DATE	TIME	C_4+ (as butane) (ppmv)	METHANE (ppmv)	ETHANE (ppmv)	ETHYLENE (ppmv)	PROPANE (ppmv)
12/13/79	1647	340	9490	490	260	240
	1655	290	7560	390	210	200
	1703	260	7060	360	210	200
	1711	290	6870	360	210	200
	1720	290	7060	390	210	200
	1728	260	6840	340	210	170
	1736	290	6910	340	210	170
	1744	290	7860	390	210	170
	1752	370	9780	490	260	240
	1800	400	11800	560	260	240
	1808	260	6660	340	210	200
	1816	370	9670	490	260	240
	1824	320	8150	420	210	200
	1832	340	8800	420	320	200
	1840	290	7490	390	260	200
	1848	344	8730	420	260	200
	1856	260	6470	290	210	170
	1904	260	6180	320	210	200
	1912	370	9930	460	320	240
	1920	340	9270	440	320	200
	1928	320	8510	440	320	200
	1936	290	7160	340	260	170
	1945	370	9670	440	320	200
	1953	260	6550	320	210	170
	2001	290	7270	360	260	200
	2009	370	9640	460	370	240
	2017	260	5820	290	210	170

(Continued)

TABLE D-2. Continued

DATE	TIME	C_4+ (as butane) (ppmv)	METHANE (ppmv)	ETHANE (ppmv)	ETHYLENE (ppmv)	PROPANE (ppmv)
12/13/79	2025	320	8330	420	260	200
	2033	290	7750	390	210	200
	2041	260	6950	340	260	200
	2217	370	11800	590	320	240
	2225	690	11100	620	370	270
	2234	640	11900	560	320	240
	2242	370	10900	590	260	240
	2251	370	11100	560	320	270
	2259	340	10700	490	260	200
	2305	420	11900	620	320	–
	2310	410	12100	620	–	270
	2318	420	11600	640	260	270
	2326	340	10900	560	260	240
	2333	500	15000	720	420	270
	2339	530	15700	720	420	270
	2347	500	14900	760	420	300
	2354	560	15600	860	270	340
12/14/79	0002	500	14100	760	320	240
	0010	450	13000	660	320	300
	0018	420	13300	660	260	270
	0026	480	13600	740	320	300
	0034	500	14200	790	320	300
	0043	450	15100	720	260	270
	0051	420	11600	540	262	–
	0056	450	17500	660	–	270
	0105	450	13000	590	320	270
	0113	500	14400	690	320	270
	0119	450	10600	520	260	240
	0135	290	7240	390	160	170

(Continued)

TABLE D-2. Continued

DATE	TIME	C_4+ (as butane) (ppmv)	METHANE (ppmv)	ETHANE (ppmv)	ETHYLENE (ppmv)	PROPANE (ppmv)
12/14/79	0141	400	10800	560	260	270
	0150	450	14200	660	320	270
	0157	420	12900	590	320	270
	0214	400	11400	620	260	240
	0226	320	7490	390	210	200
	0234	420	7820	420	260	200
	0242	370	8360	440	210	200
	0250	480	15300	720	370	300
	0259	420	13500	640	320	240
	0307	340	11400	560	260	270
	0316	450	15000	740	370	270
	0323	530	16000	790	420	300
	0330	420	12600	620	320	270
	0336	420	13400	620	260	240
	0342	450	12700	640	320	270
	0351	370	11100	560	262	240
	0359	480	14000	740	260	270
	0408	320	8620	440	260	170
	0415	400	10000	520	260	200
	0423	320	9090	460	210	200
	0429	340	8550	440	210	200
	0437	320	7890	420	210	200
	0454	320	8260	440	210	200
	0500	260	6110	340	210	200
	0507	340	9020	490	160	170
	0515	320	8950	460	210	200
	0523	320	8470	440	210	240

(Continued)

TABLE D-2. Continued

DATE	TIME	C_4+ (as butane) (ppmv)	METHANE (ppmv)	ETHANE (ppmv)	ETHYLENE (ppmv)	PROPANE (ppmv)
12/14/79	0531	320	7820	420	210	200
	0539	320	9200	490	210	200
	0546	320	8000	440	210	200
	0554	340	8910	460	260	240
	0602	320	8260	440	210	200
	0611	320	8690	440	210	200
	0619	340	9160	490	210	200
	0627	340	9670	560	210	240
	0633	370	9090	490	210	200
	0639	320	7560	440	160	240

TABLE D-3. PRODUCT GAS MAJOR GASES CONCENTRATIONS

DATE	TIME	H_2 %	CO_2 %	O_2 %	N_2 %	CO %	TOTALS %
12/13/79	1434	16.6	7.01	1.14	46.8	26.9	98.4
	1447	16.6	8.54	1.14	48.0	24.0	98.3
	1519	13.2	9.16	1.14	52.4	21.0	96.9
	1532	14.9	8.75	1.14	49.2	22.5	96.5
	1544	16.6	7.72	1.00	47.1	25.4	97.8
	1556	16.6	7.11	1.14	46.8	26.2	97.8
	1609	16.6	7.21	1.00	47.4	26.2	98.4
	1621	18.2	7.11	1.00	46.5	26.9	99.7
	1633	16.6	7.01	1.00	46.2	26.9	97.7
	1645	16.6	7.11	1.14	46.2	26.9	98.0
	1658	16.6	6.70	1.00	44.7	26.2	95.2
	1710	16.6	6.70	1.14	45.3	27.6	97.3
	1722	16.6	6.80	1.14	46.2	27.6	98.3
	1735	18.2	6.80	1.14	46.2	27.6	99.9
	1747	16.6	6.80	1.00	46.5	27.6	98.5
	1759	16.6	6.60	1.14	46.2	26.9	97.4
	1812	18.2	6.49	1.14	45.3	27.6	98.7
	1824	16.6	6.60	1.14	45.6	26.9	96.8
	2014	16.6	8.34	1.14	47.7	24.7	98.5
	2027	16.6	8.13	1.14	47.7	25.4	99.0
	2039	16.6	7.93	1.14	47.7	25.4	98.8
	2051	16.6	7.82	1.28	47.4	25.4	98.5
	2104	16.6	8.03	1.14	47.7	25.4	98.9
	2116	16.6	8.03	1.14	47.7	25.4	98.9
	2138	16.6	7.52	1.14	46.2	26.9	98.4
	2150	16.6	7.31	1.00	45.0	26.2	96.1
	2203	16.6	7.01	1.00	45.0	26.9	96.5
	2215	16.6	7.11	1.14	46.8	25.4	97.0
	2227	16.6	7.21	1.14	45.3	26.9	97.2

(Continued)

TABLE D-3. Continued

DATE	TIME	H_2 %	CO_2 %	O_2 %	N_2 %	CO %	TOTALS %
12/13/79	2239	16.6	6.70	1.00	44.4	26.9	95.6
	2252	16.6	6.90	1.00	45.3	26.9	96.7
	2304	16.6	7.11	1.00	44.7	26.9	96.3
	2316	16.6	6.29	1.00	43.6	28.4	95.9
	2329	18.2	6.70	1.14	45.6	29.8	101.4
	2341	16.6	7.72	1.14	49.8	26.9	102.2
	2353	16.6	7.11	1.14	45.3	27.6	97.8
12/14/79	0006	16.6	6.39	1.00	44.1	28.4	96.5
	0018	19.9	8.03	1.14	46.2	27.6	102.9
	0030	16.6	8.85	1.28	47.4	23.2	97.3
	0042	16.6	7.82	1.00	45.0	25.4	95.8
	0055	23.2	8.44	0.85	37.9	26.9	97.3
	0107	14.9	7.11	0.85	43.3	24.7	90.9
	0119	14.9	6.90	1.00	43.0	25.4	91.2
	0132	14.9	6.80	1.00	43.0	24.7	90.4
	0144	14.9	6.60	1.00	43.3	24.7	90.5
	0156	16.6	6.90	1.00	44.1	26.2	94.8
	0208	14.9	6.49	0.85	40.3	24.0	86.5
	0221	13.2	6.29	1.00	40.0	24.0	84.5
	0233	14.9	6.08	1.00	39.7	24.0	85.7
	0245	14.9	6.19	1.00	40.6	25.4	88.1
	0258	16.6	5.88	1.00	40.9	25.4	89.8
	0310	14.9	5.88	0.85	40.9	25.4	87.9
	0322	16.6	6.08	1.14	42.1	26.2	92.1
	0334	16.6	5.98	1.00	41.5	26.2	91.3

(Continued)

TABLE D-3. Continued

DATE	TIME	H_2 %	CO_2 %	O_2 %	N_2 %	CO %	TOTALS %
12/14/79	0347	16.6	6.08	1.14	42.4	26.9	93.1
	0359	16.6	5.88	1.14	42.7	26.9	93.2
	0411	16.6	5.68	1.14	41.8	26.9	92.1
	0424	16.6	5.68	1.00	42.1	26.9	92.3
	0436	13.2	5.37	1.14	40.3	26.2	86.2
	0448	16.6	5.47	1.14	41.2	26.2	90.6
	0500	16.6	5.98	1.14	42.7	27.6	94.0
	0513	16.6	5.78	1.00	42.1	26.9	92.4
	0525	16.6	6.08	1.14	42.7	26.9	93.4
	0537	16.6	8.13	1.00	41.2	24.0	90.9
	0550	14.9	8.34	1.42	42.1	21.0	87.8
	0602	16.6	7.01	1.14	41.2	23.2	89.2
	0614	16.6	6.80	1.14	41.5	24.0	90.0
	0627	14.9	5.98	1.14	38.8	24.7	85.5
	0639	16.6	5.98	1.00	38.8	24.7	87.1
	0651	16.6	5.78	1.14	38.2	25.4	87.1
	0704	16.6	5.57	1.14	38.2	25.4	86.9
	0716	14.9	5.68	1.00	38.0	25.4	85.2
	0728	16.6	5.37	1.00	38.2	25.4	86.6
	0740	16.6	5.27	1.00	37.6	25.4	85.9
	0753	16.6	5.16	1.00	37.6	25.4	85.8
	0805	14.9	5.16	1.00	37.3	25.4	83.8
	0817	16.6	4.96	1.00	36.8	26.2	85.6
	0830	16.6	4.75	1.14	37.9	27.0	87.4
	0842	16.6	4.86	1.14	39.1	27.6	89.3
	0854	16.6	4.96	1.14	39.7	27.6	90.0

(Continued)

TABLE D-3. Continued

DATE	TIME	H_2 %	CO_2 %	O_2 %	N_2 %	CO %	TOTALS %
12/14/79	0907	16.6	5.06	1.00	43.8	27.6	94.1
	0919	18.2	6.29	1.00	42.4	27.6	95.5
	0931	16.6	8.64	1.14	43.8	23.2	93.4
	0943	14.9	8.64	1.14	45.0	22.5	92.2
	0956	14.9	8.03	1.14	45.3	22.5	91.9
	1008	16.6	8.54	1.14	43.3	25.4	95.0
	1020	16.6	7.11	1.14	42.4	25.4	92.6
	1033	16.6	6.90	1.00	42.1	25.4	92.0
	1045	16.6	6.70	1.14	42.1	26.2	92.7
	1057	16.6	6.80	1.00	41.2	25.4	91.0
	1110	16.6	6.49	1.14	40.9	25.4	90.5
	1122	14.9	6.19	1.00	41.2	26.2	89.5
	1134	16.6	6.29	1.14	42.4	25.4	91.8
	1159	16.6	6.08	1.14	41.2	26.2	91.2
	1211	16.6	6.08	1.14	41.5	26.9	92.2
	1223	16.6	6.19	1.14	41.2	26.2	91.3
	1236	16.6	5.98	1.00	42.1	26.2	91.9
	1248	16.6	6.29	1.14	43.6	27.6	95.2
	1300	14.9	5.98	1.00	41.5	26.9	90.3
	1312	16.6	6.08	1.14	41.8	26.9	92.5
	1324	14.9	6.70	1.14	44.4	25.4	92.5
	1337	14.9	6.70	1.14	43.3	25.4	91.4
	1349	14.9	9.56	1.14	44.7	22.5	92.8

TABLE D-4. AVERAGE GAS COMPOSITIONS DETERMINED BY PROCESS GAS CHROMATOGRAPHS

H_2	1.4 E7 $\mu g/Nm^3$	16.9%
CO	3.0 E8 $\mu g/Nm^3$	25.9%
CO_2	1.2 E8 $\mu g/Nm^3$	6.75%
O_2/Ar*	1.6 E7 $\mu g/Nm^3$	1.08%+
N_2	5.0 E8 $\mu g/Nm^3$	43.3%
CH_4	6.5 E6 $\mu g/Nm^3$	9870 ppm
C_2H_6	6.1 E5 $\mu g/Nm^3$	497 ppm
C_2H_4	3.0 E5 $\mu g/Nm^3$	260 ppm
C_3H_8	4.0 E5 $\mu g/Nm^3$	225 ppm
C_4+ (as C_4H_{10})	8.5 E5 $\mu g/Nm^3$	358 ppm
H_2S	1.5 E6 $\mu g/Nm^3$	1100 ppm
COS	3.0 E5 $\mu g/Nm^3$	121 ppm
		95.2%

Notes:

Dry Molecular Weight = 23.3.
Average Percent Moisture = 25.6%.

*O_2/Ar are measured as a single component; O_2 and Ar concentrations were estimated using the following equations:

$$O_2 = O_2/\text{Ar Conc.} - \text{Ar}$$

$$\text{Ar} = \frac{\text{Conc. } N_2 \text{ P.G.}}{\text{Conc. } N_2 \text{ Air}} \times \text{Conc. Ar Air}$$

+O_2 = 6.28 E6 $\mu g/Nm^3$ = 0.48%
Ar = 9.80 E6 $\mu g/Nm^3$ = 0.60%
1.08%

APPENDIX E

ON-SITE ANALYTICAL RESULTS

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E.1.0 INTRODUCTION

Radian Corporation provided on-site analytical support for the Riley Gas Producer test simultaneously with process sampling. In addition, certain samples were preserved and sent to Radian's Austin lab for analysis.

Some wastewater parameters in samples of the ash pan water and service water were analyzed on-site. The more stable parameters were analyzed in preserved samples at the Austin lab. All samples for trace metal analyses were preserved for later analysis.

Impinger samples from the product gas stream were analyzed on-site for hydrogen cyanide and ammonia. Due to problems with tars, thiocyanate was determined in Austin following proper preservation. Trace metal samples of the product gas collected in impingers were returned to the Austin lab.

Solid samples required no preservation. They were returned to Austin for trace metal analysis, leaching studies, and bioassay testing.

E.2.0 WASTEWATER ANALYSES

Ash pan water and service water samples were taken at intervals, preserved, and then analyzed at the end of the sampling run. Table E-1 presents the wastewater parameters and product gas parameters analyzed, preservation techniques, and the location at which each analysis was performed. Table E-2 presents the water sampling schedule, and the results of the preliminary analyses.

In the mobile lab, the samples were logged and analyzed for pH, conductivity, and sulfide. These values were used to identify samples for further analysis. The samples were then preserved for the various parameters listed in Table E-1. Analytical results of the water quality analyses are listed in Table E-3.

E.3.0 IMPINGER SAMPLE ANALYSES

Gaseous samples of ammonia, hydrogen cyanide, and trace elements were collected by impingers. Ammonia was collected using two 10% H_2SO_4 impingers in series. Table E-4 presents the ammonia results for the product gas. The collection efficiency of the first impinger was greater than 97 percent.

Hydrogen cyanide was collected using 5 percent NaOH in two impingers in series. The collection efficiency of the first was 98%. The hydrogen cyanide impingers were analyzed for thiocyanate (SCN−) in addition to cyanide (HCN). Sulfide reacts with cyanide in aqueous media to produce SCN−. Therefore, HCN values were corrected to include the cyanide contribution of SCN−. Table E-5 presents the analytical results for HCN and SCN−.

Vapor phase trace elements were collected using two different systems simultaneously. System 1 consisted of two 10 percent Ultrex HNO_3 impingers

TABLE E-1. WASTEWATER AND PRODUCT GAS PARAMETERS AND PRESERVATION METHODS

Parameter	Location	Method	Preservation
pH	OS^x	Corning Model 3D pH meter with combination electrode	None
Conductivity	OS	YSI Model 33 conductivity meter	None
Phosphate	Austin Lab	Colorimetric	H_2SO_4, pH<2, cool
Chloride	Austin Lab	Colorimetric	Cool
Fluoride	Austin Lab	Specific ion electrodes	Cool
Sulfide	OS	Titrimetric	None
Nitrate	OS	Colorimetric	Cool
Cyanide	OS	Distillation/colorimetric	$S^=$ removed, NaOH, pH>12, cool
Thiocyanate	Austin Lab	Extinction/colorimetric	$S^=$ removed, NaOH, pH>12, cool
Sulfate	Austin Lab	Turbidimetric	Cool
Ammonia	OS	Distillation/titrimetric	H_2SO_4, pH<2, cool
COD	Austin Lab	Reflux/titrimetric	H_2SO_4, pH<2, cool
BOD	Austin Lab	Digestion/titrimetric	Cool
TOC	Austin Lab	Dohrmann Model 54 TOC analyzer	H_2SO_4, pH<2, cool
TSS	Austin Lab	Gravimetric	Cool
TDS	Austin Lab	Gravimetric	Cool
Phenol	Austin Lab	Distillation/colorimetric	H_3PO_4, pH<4, cool
Trace Metals	Austin Lab	SSMS/AAS/ICPES	HNO_3, pH<2

x On-site analysis

TABLE E-2. WATER SAMPLING SCHEDULE AND RESULTS OF PRELIMINARY ANALYSES

Water	Time	Date	pH	µmho/cm	mgS=/1
Ash pan	0850	12/13	9.2	1700	0.4
Ash pan (during plow)	1010	12/13	5.0	415	0.4
Ash pan	1100	12/13	8.5	800	1.2
Ash pan	1415	12/13	8.2	430	0.4
Ash pan	1715	12/13	8.9	990	2.0
Ash pan	1930	12/13	10.7	3620	7.2
Ash pan	2145	12/13	10.4	2100	5.6
Ash pan	0000	12/14	10.2	1550	4.8
Ash pan	0300	12/14	11.0	1920	7.2
Ash pan	0640	12/14	11.3	2900	17.6
Service	1020	12/13	4.3	47	<.4
Service	1530	12/13	4.8	60	<.4
Service	0100	12/14	6.2	62	<.4

TABLE E-3. RESULTS OF WATER QUALITY ANALYSES

	Service Water	Ash Pan Water			
Time Date	1020 12-13	1415 12-13	1930 12-13	0000 12-14	0640 12-14
pH	4.3	8.2	10.7	10.2	11.3
µmho/cm	47	430	3620	1550	2900
$S^=$ mg/l	0.4	0.4	7.2	4.2	18
CN^- mg/l	<.2	0.3	NA	0.9	NA
SCN^- mg/l	<4	<4	<4	<4	<4
NH_4^+ mg/l	<30	<30	<30	<30	<30
NO_3^- mg/l	<.02	<.02	<.02	<.02	<.02
$SO_4^=$ mg/l	6.1	130	1870	540	1380
$PO_4^=$ mg/l	<.05	<.05	.07	<.05	.06
F^- mg/l	<.05	.11	.59	.30	.71
Cl^- mg/l	14	11	76	48	110
TDS mg/l	52	385	3050	1250	2460
TSS mg/l	3.4	14	102	5.3	32
Phenol mg/l	<.05	.83	2.0	1.5	2.7
TOC mg/l	7.3	11	7.5	9.4	15
COD mg/l	23	44	44	52	87
BOD mg/l	1.7	8.4	26	18	44

NA - Not Analyzed

TABLE E-4. PRODUCT GAS AMMONIA CONCENTRATION

Run	Time	Date	Impinger	μgNH$_3$	Total μgNH$_3$	Nm^3*	μgNH$_3$/Nm^3	Vppm*
1	1311- 1344	12/13	1 2	200,000±11,000 <6000	200,000	0.2526	7.8 E5	1120
2	1525- 1555	12/13	1 2	205,000±1300 <6000	205,000	0.2608	7.9 E5	1130
3	0433- 0502	12/14	1 2	<6000 <6000	<6000	0.3137	<3.8 E4	<55
4	0600- 0630	12/14	1	<6000 <6000	<6000	0.2460	<4.9 E4	<70

*Nm^3, 25°C, 101 kPa, dry

TABLE E-5. PRODUCT GAS HYDROGEN CYANIDE CONCENTRATION

Run	Time	Date	Impinger	µg HCN	µg SCN⁻	HCN Content of SCN⁻	Total µg HCN	Sample Gas Volume SCM*	µg HCN/SCM	ppm HCN
1	1305-1340	12/13	1	34,100 ± 730	34,200	15,900	50,700	0.3100	1.6 E5	150
			2	710	<790	<370				
2	1445-1520	12/13	1	29,100 ± 310	11,700	5,450	34,800	0.3050	1.1 E5	100
			2	280	<840	<390				
3	0452-0526	12/14	1	350 ± 41	<820	<380	430	0.2582	1.7 E3	1.5
			2	79	<820	<380				
4	0600-0632	12/14	1	317 ± 104	<750	<350	430	0.2385	1.8 E3	1.6
			2	113	<750	<350				
5	0900-0923	12/14	1	35,800 ± 80	21,900	10,200	47,500	0.1802	2.6 E5	240
			2	960	1,160	540				

*SCM, 25°C, 101 kPa, dry

followed by two 10 percent NaOH impingers followed by a single impinger containing activated charcoal to trap metals that were possibly carried over from the previous impinger solutions. System 2 consisted of two impingers containing silver persulfate backed up by activated charcoal. All impinger solutions and charcoal samples were returned to Austin for analysis.

E.4.0 VAPOR PHASE GAS CHROMATOGRAPHIC ANALYSES

Grab samples of the product gas were taken for the gas chromatographic analysis of:

- major gases: H_2, O_2 + Ar, N_2, CO_2, CO and CH_4
- volatile sulfur species: H_2, COS, SO_2, CH_3SH, $(CH_3)_2S$, and CS_2
- light hydrocarbons: CH_4, C_2H_4, C_2H_6, and C_3–C_6 paraffins + olefins, and
- BTX: benzene, toluene and xylenes.

In addition, the pokehole gas was analyzed for major gases and fugitive emission samples were taken for BTX analysis. Major gas, volatile sulfur species and light hydrocarbon samples were taken in silanized glass bombs and analyzed immediately. BTX samples were taken using glass tubes packed with activated charcoal as a sorption media. Tables E-6 through E-8 present the product gas concentrations as determined by the on-site laboratory gas chromatograph for major gases, sulfur species and hydrocarbons.

E.4.1 Major Gases

The major gases analyses were carried out on-site under the following conditions:

Instrument:	Fisher Gas Partitioner Model 1200 TCD-GC
Column 1:	2 m x 3.1 mm, Porapak PQ
Column 2:	3.4 m x 4.8 mm, Molecular Sieve 13x
Carrier:	8.5% Hydrogen in Helium at 28 ml/min
Oven Temperature:	50°C
Bridge Current:	255 mA

The instrument calibration for the major gases analyses was performed on-site using certified standard gas mixtures with the compositions shown in Table E-9.

Figures E-1 through E-5 show the calibration curves that were used. The 95% confidence limit (2σ) is included for each calibration point. Each point is the result of 2 individual determinations.

TABLE E-6. PRODUCT GAS MAJOR GASES ANALYSIS[1]

DATE	TIME	CO_2	H_2	O_2	N_2	CO	CH_4	TOTAL SAMPLE
12-10-79	1530	3.2	16.5	1.5	42.3	27.5	1.5	92.5
12-12-79	1525[2]	4.2	19.4	0.9	44.	28.6	2.0	99.1
	1020	3.8	18.8	1.0	46.	28.5	1.3	99.4
12-13-79	0835[2]	5.2	18.8	2.6	51.1	27.1	1.5	106.3
	1102	2.1	6.9	12.6	68.4	10.5	0.7	101.2
	1505[2]	5.6	10.9	6.6	58.4	18.6	1.0	101.1
	1520	5.2	11.5	6.7	56.7	17.3	1.0	98.4
	1745	4.8	14.4	5.3	53.4	22.3	1.2	101.4
	2020	3.9	8.9	10.2	64.7	13.3	0.8	101.8
	2320[2]	10.2	20.	2.1	50.5	20.9	1.3	105.
12-15-79	0130[2]	7.3	4.4	1.3	46.1		1.5	

[1] Concentration in volume percent.

[2] Indicates condensate present in sample bomb.

TABLE E-7. PRODUCT GAS HYDROCARBONS ANALYSIS[1]

DATE	TIME	CH_4	C_2H_6	C_2H_4	C_3	C_4	C_5	C_6
12-10-79	1530	15300	946	608	551	261	155	255
12-12-79	1525[2]	13700	966	1000	606	294	200	305
12-13-79	0835[2]	13900	872	927	543	268	187	275
	1520	7880	488	967	365	782	169	455
	1745	9650	624	804	430	237	148	401
	2020	5990	376	751	284	160	78	222
12-14-79	2320[2]	12800	762	719	482	246	172	371
12-15-79	0130[2]	13100	807	727	520	265	203	341

[1] Concentration in parts per million (volume/volume).

[2] Indicates condensate present in sample bomb.

TABLE E-8. PRODUCT GAS SULFUR SPECIES ANALYSIS[1]

DATE	TIME	H_2S	COS	CH_3SH	$(CH_3)_2S$	CS_2
12-10-79	1530	1080	146	117	13.7	13.2
12-12-79	1525[2]	1790	161	121		
12-13-79	0835[2]	1600	144	124	13.7	6.3
	1520	1070	158	54.1	5.3	6.2
	1745	1540	134	82.2	8.5	6.6
	2020	827	131	32.2	4.2	4.0
12-14-79	2320[2]	1880	112	110	11.0	4.6
12-15-79	0130[2]	1830	120	120	11.9	7.4

[1] Concentration in parts per million (volume/volume).

[2] Indicates condensate present in sample bomb.

TABLE E-9. STANDARD GAS MIXTURES USED FOR MAJOR GASES CALIBRATION

Species	Standard 1 (%)	Standard 2 (%)	Standard 3 (%)	Standard 4 (%)
CO_2	19.7	1.99	–	10.1
H_2	29.8	19.87	1.47	9.9
O_2	0.85	1.99	19.8	0.97
N_2	24.3	33.97	77.76	64.99
CH_4	0.62	2.10	–	4.04
CO	24.7	40.08	0.97	10.0

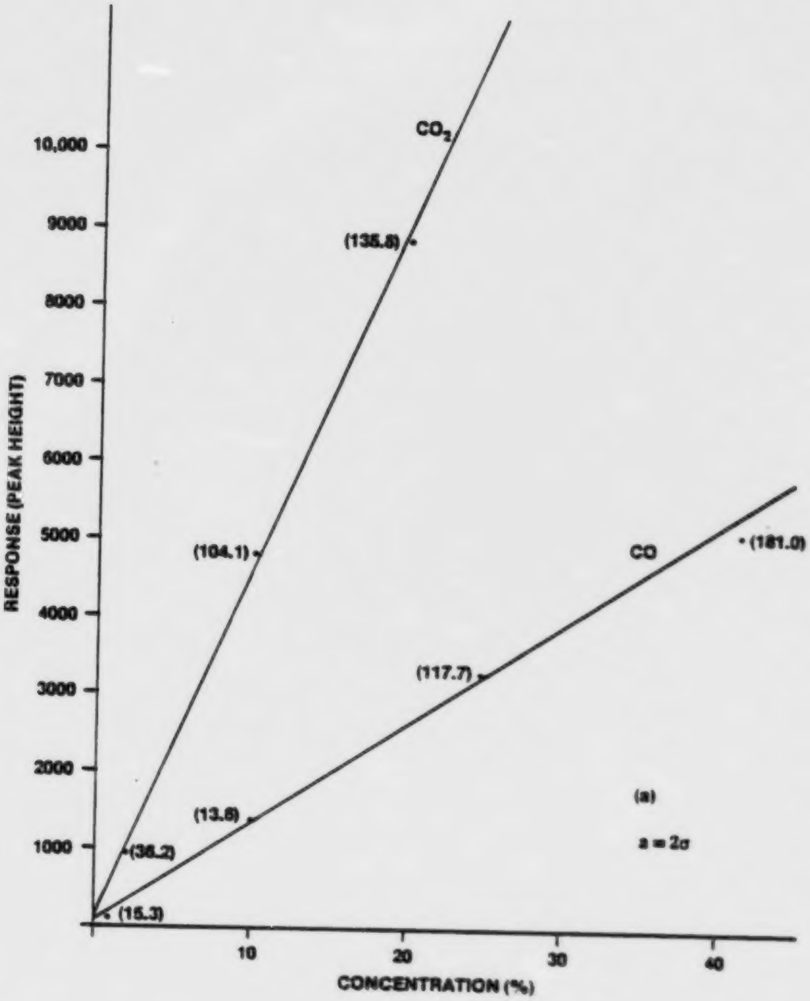

Figure E-1. CO_2 and CO Calibration Curves

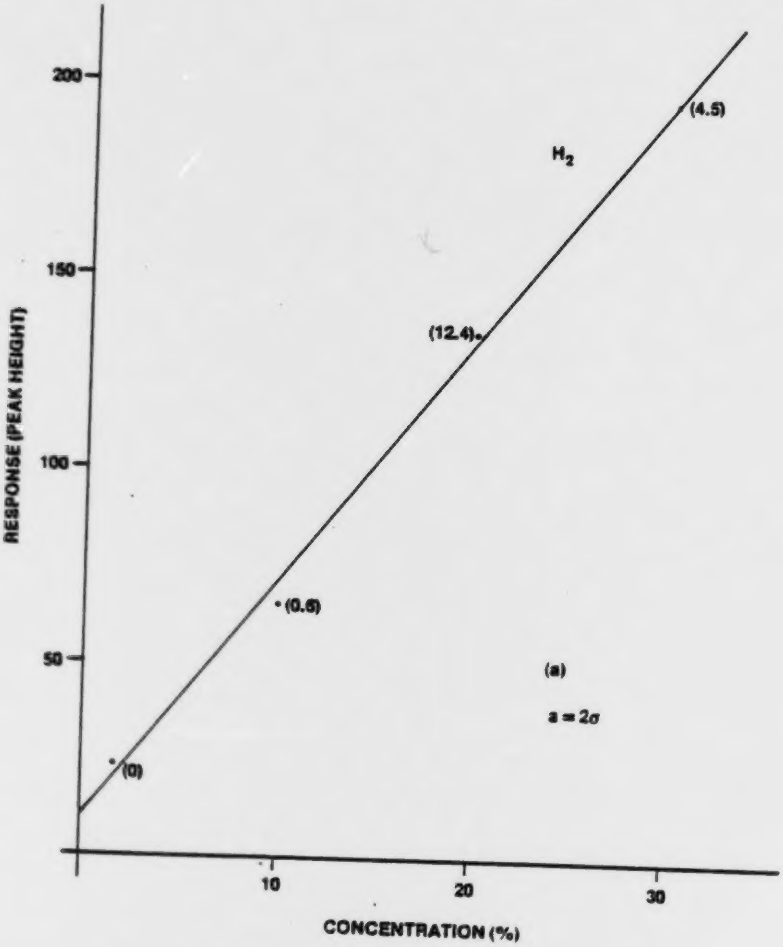

Figure E-2. H_2 Calibration Curve

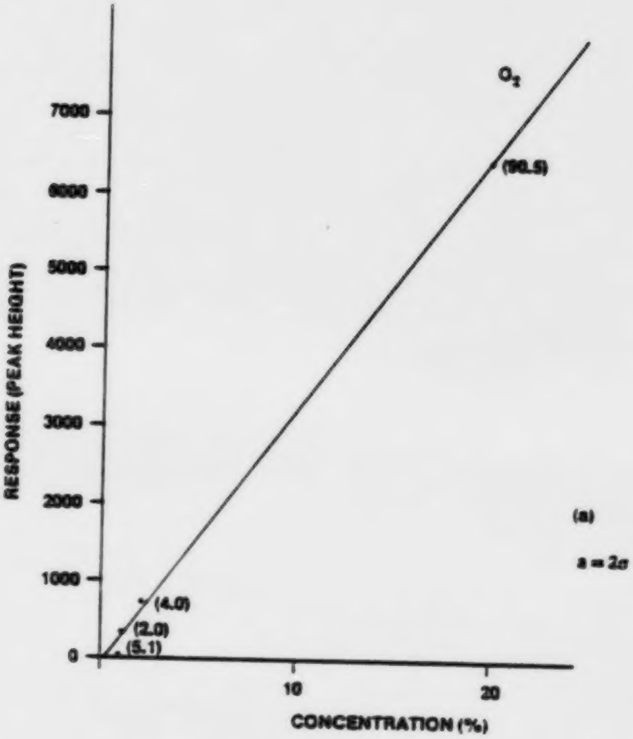

Figure E-3. O$_2$ Calibration Curve

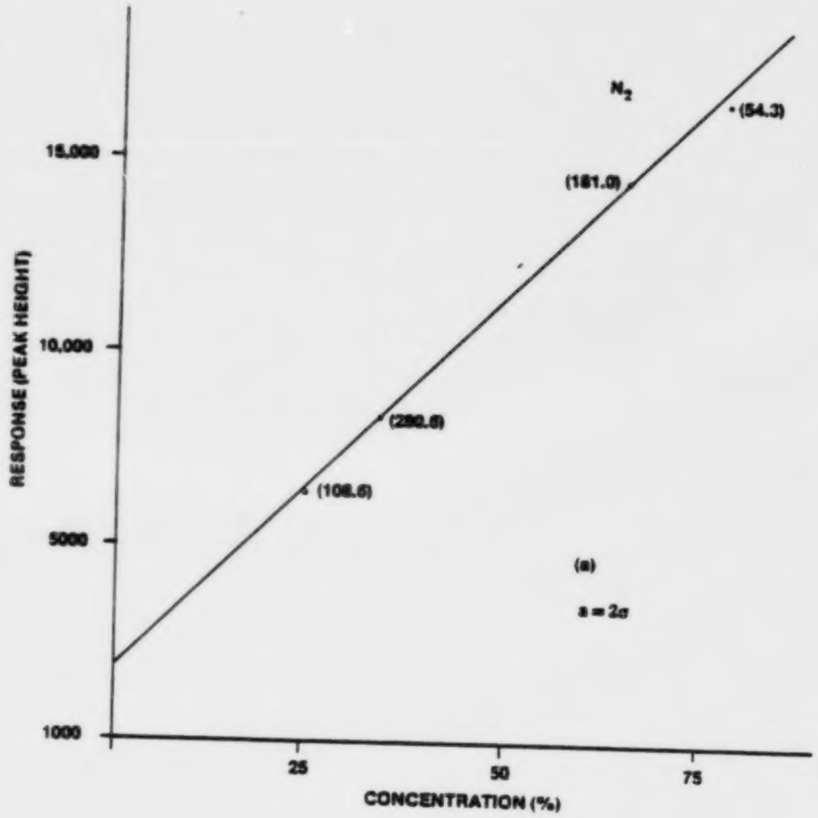

Figure E-4. N$_2$ Calibration Curve

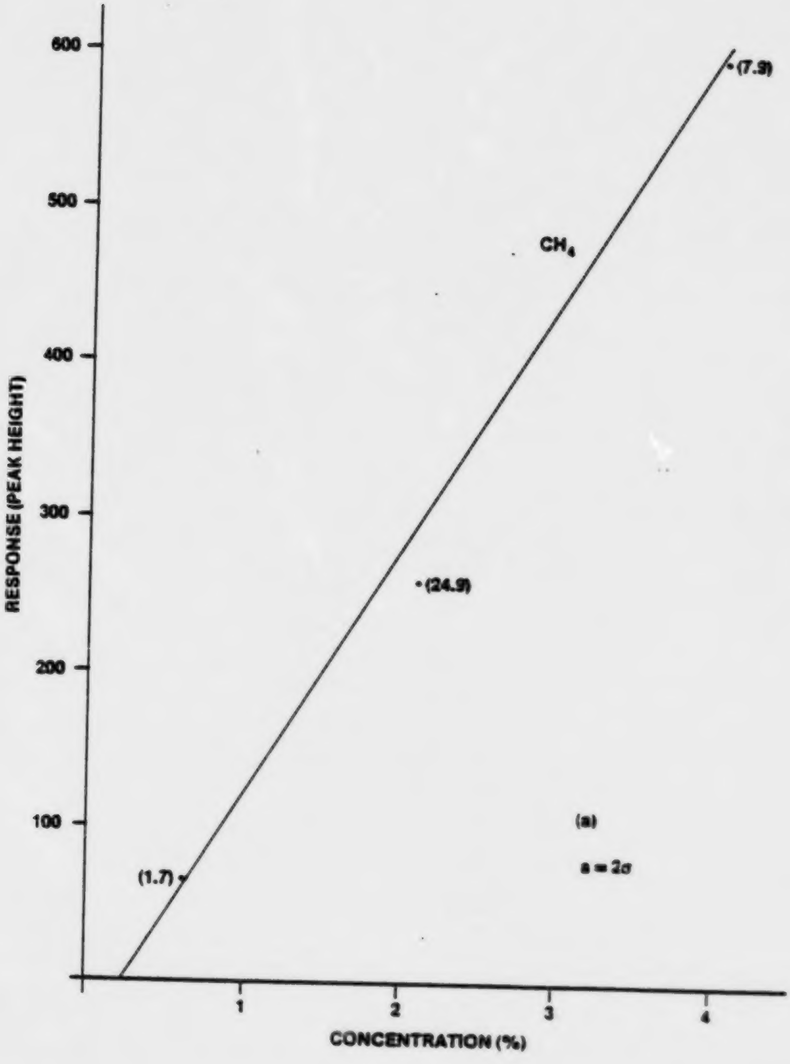

Figure E-5. CH$_4$ Calibration Curve

E.4.2 Volatile Sulfur Species

Volatile sulfur species were analyzed on-site using the following instrument parameters:

Instrument:	Tracor Model 560 FPD-GC
Column:	3.05 m x 3.1 mm Teflon , 1% TCEP and 0.5% H_3PO_4 on 60/80 mesh Carbopack B
Carrier:	Nitrogen at 20 ml/min
Detector Temperature:	150°C
Sampling loop:	25 1 or 1 ml
Oven program:	30°C for 7 min; 10°C/min to 120°C: 120°C for 10 min.

The instrument calibration was performed on-site using certified Metronics permeation tubes and zero grade nitrogen at known flow rates. Figures E-6 through E-11 show calibration curves for H_2S, COS, SO_2, CH_3SH, $(CH_3)_2S$ and CS_2 on log x log plots.

E.4.3 Light Hydrocarbons

C_1–C_6 hydrocarbons were analyzed on-site using the following instrument parameters:

Instrument:	Tracor Model 560 FID-GC
Column:	1.8 m x 3.1 mm OD stainless steel, 80/100 mesh Porapak Q.
Carrier:	Nitrogen at 20 ml/min
Injector Temperature:	200°C
Detector Temperature:	300°C
Sample Loop:	5.0 ml
Oven Program:	50°C for 2 min; 10°C/min to 200°C: 200°C hold until baseline reestablished

Calibration was carried out on-site using certified gas mixtures of C_1–C_6 paraffins and C_2–C_6 olefins. Methane, ethane and ethene were quantified individually. For C_3–C_6 hydrocarbons, an average response factor for the paraffin and corresponding olefin for each carbon number was used. Calibration curves are presented in Figure E-12.

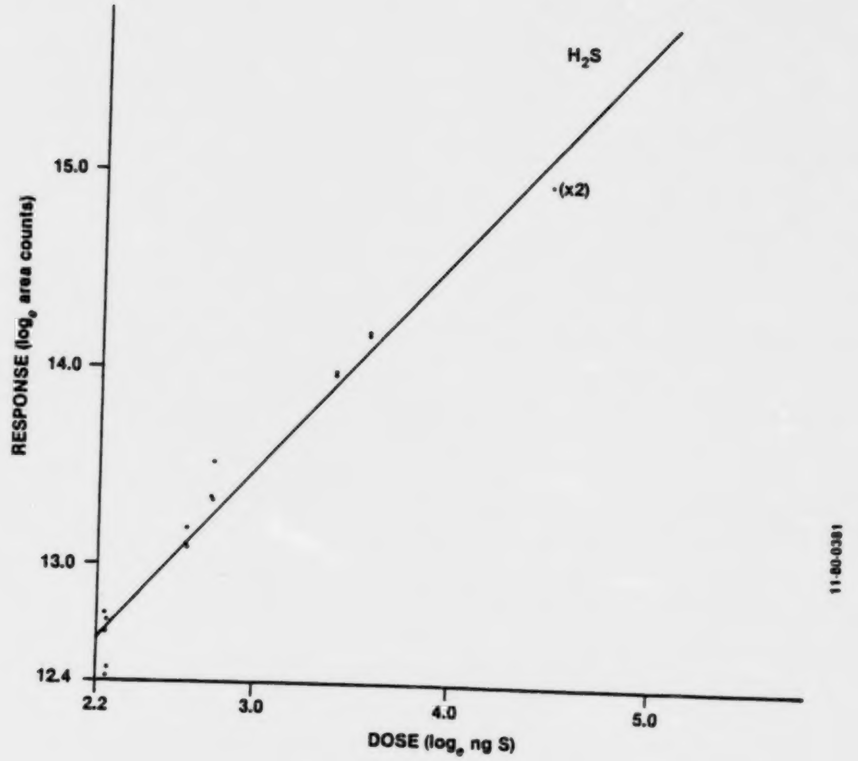

Figure E-6. H_2S Calibration Curve

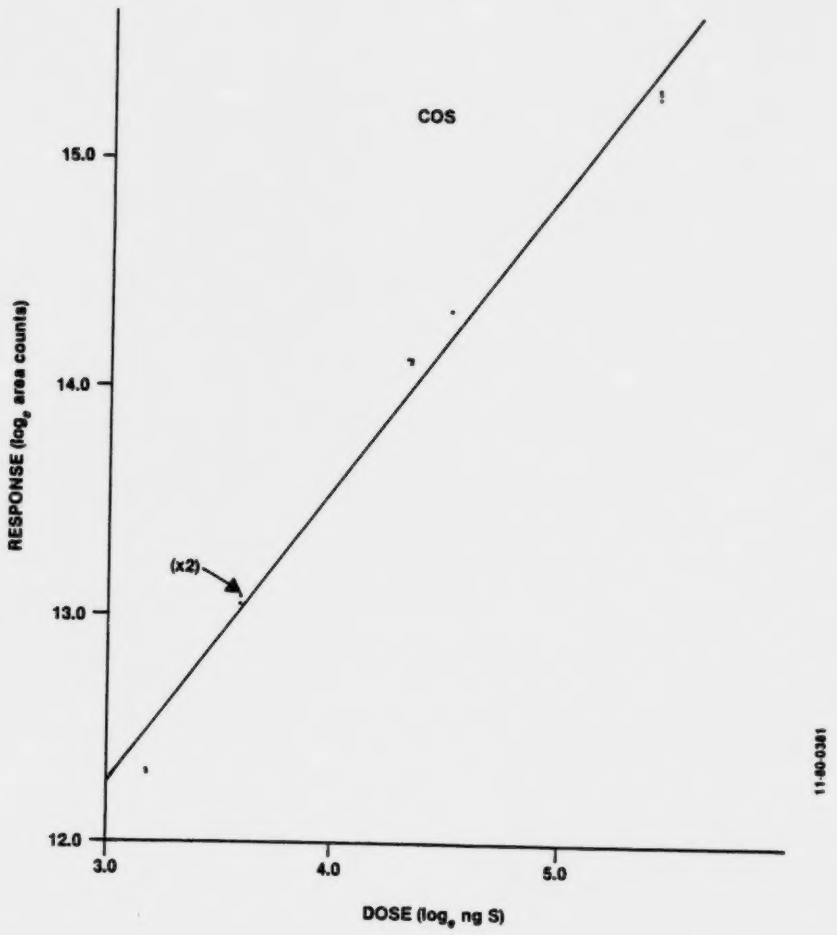

Figure E-7. COS Calibration Curve

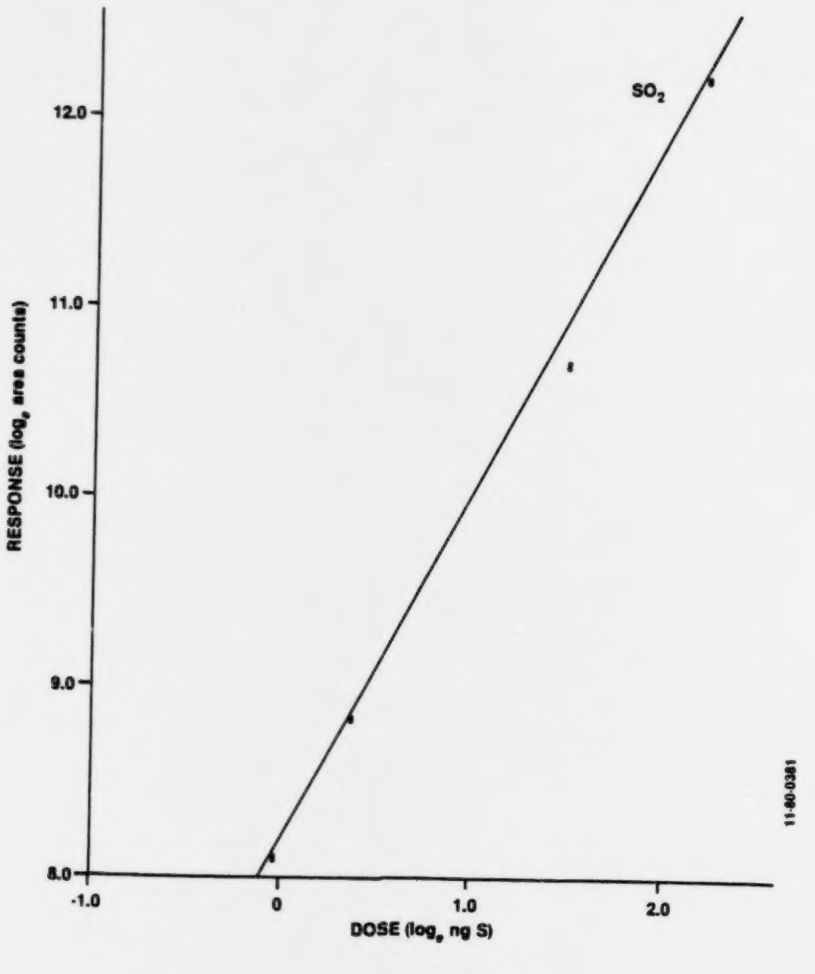

Figure E-8. SO$_2$ Calibration Curve

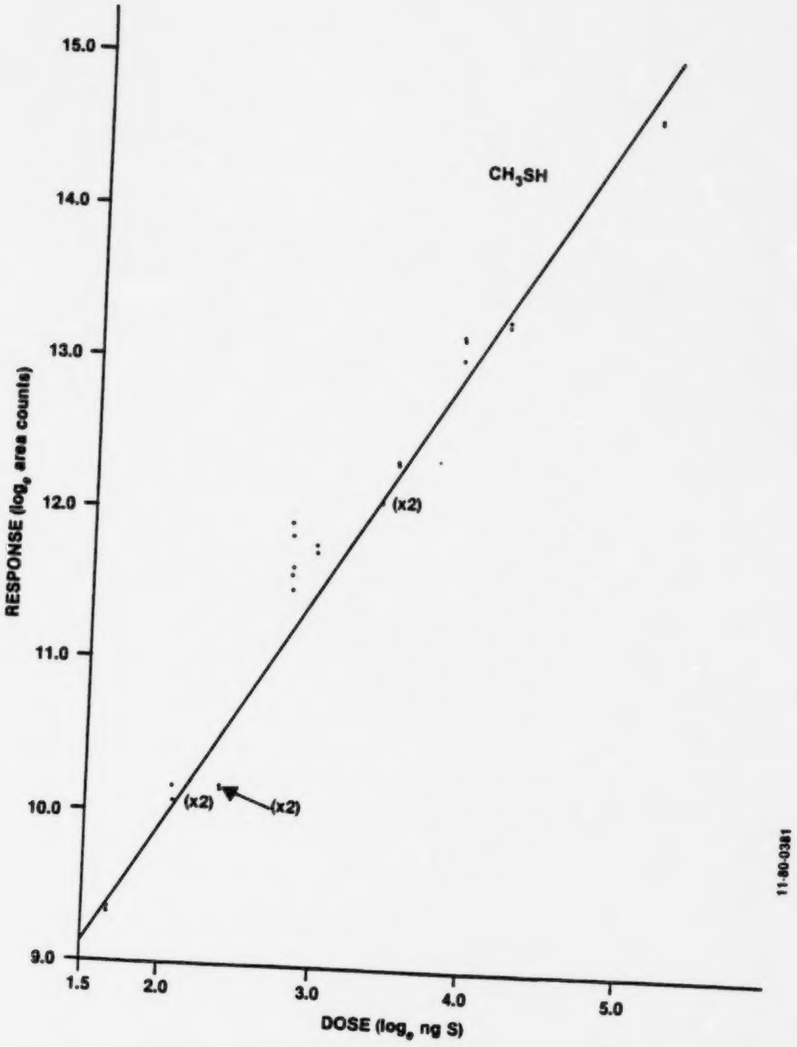

Figure E-9. CH$_3$SH Calibration Curve

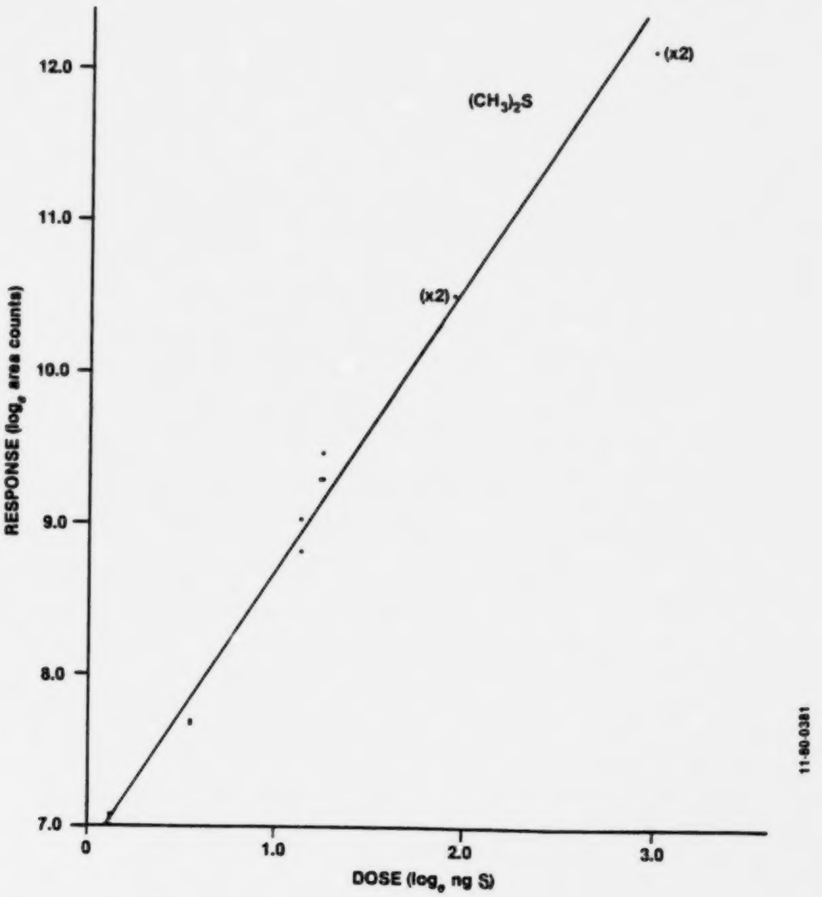

Figure E-10. $(CH_3)_2S$ Calibration Curve

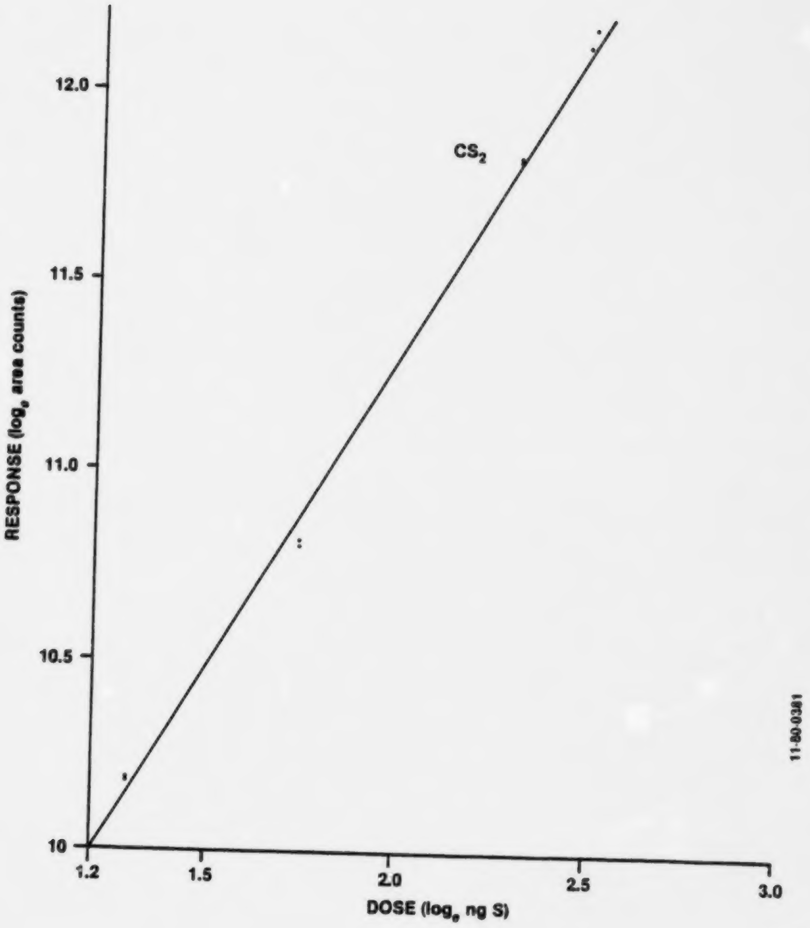

Figure E-11. CS_2 Calibration Curve

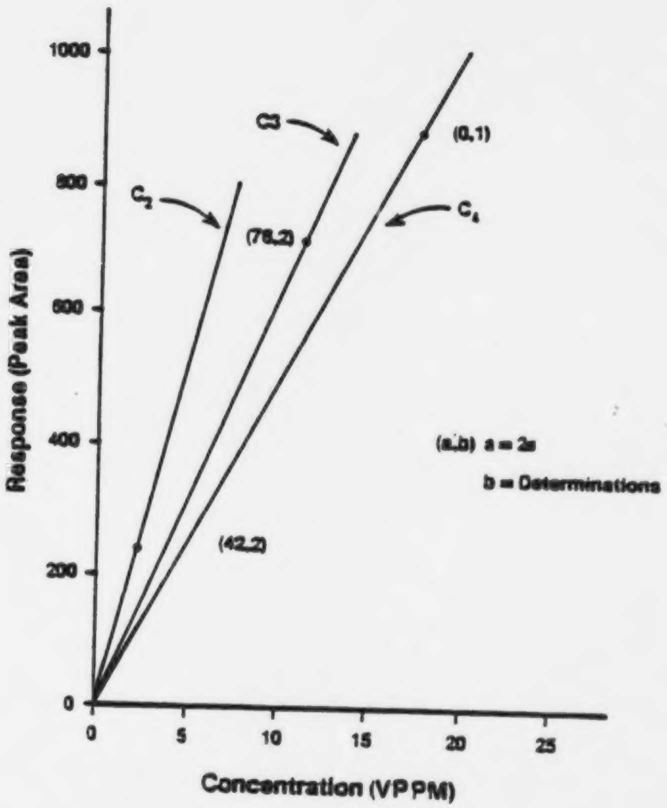

Figure E-12. C_2-C_4 Olefins Calibration Curves

APPENDIX F
ANALYTICAL DATA

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F.1.0 INORGANIC ANALYSIS RESULTS

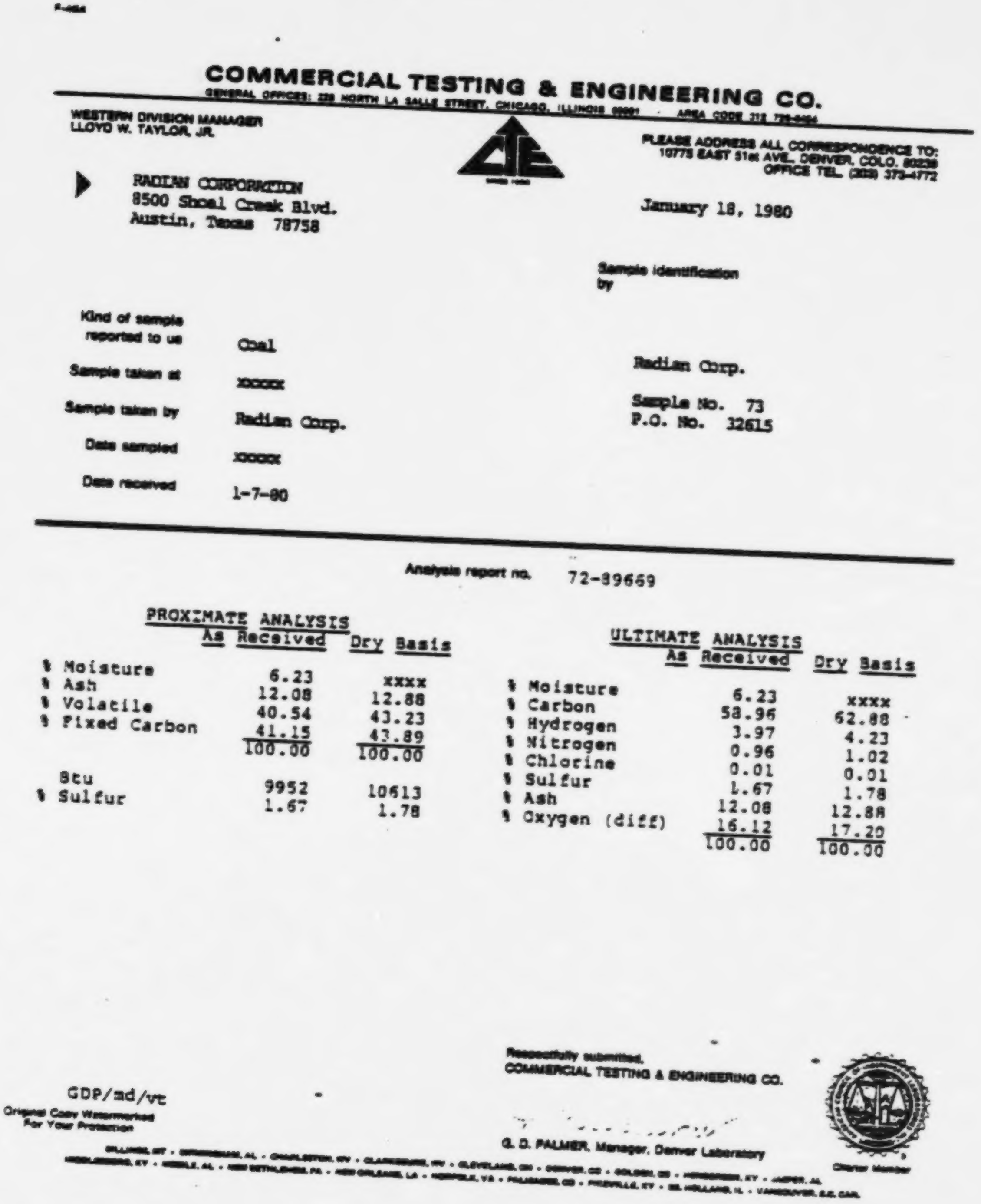
This section presents inorganic analysis results, including those for ultimate and proximate analyses (Section F.1.1), particle size distribution (Section F.1.2), the moisture content of the lignite (Section F.1.3), radioactivity (Section F.1.4), trace element analyses (Section F.1.5), and water quality analyses (Section F.1.6).

F.1.1 Ultimate and Proximate Analyses

Listed below are the CT+E sample numbers used on the data sheets in this section, the corresponding Radian sample numbers and the sample descriptions.

CT+E Sample No.	Radian Sample No.	Sample Description
73	RM-73	Lignite
75	RM-75	Lignite
76	RM-76	Lignite
77	RM-77	Lignite
81	RM-81	Lignite
82	RM-82	Lignite
95	RM-95	Gasifier Ash
98	RM-98	Gasifier Ash
126	RM-126	Gasifier Ash
147	RM-147	Gasifier Ash
149	RM-149	Gasifier Ash
153	RM-153	Cyclone Dust
154	RM-154	Cyclone Dust
157	RM-157	ESP Tar

TABLE F-1. PROXIMATE AND ULTIMATE ANALYSIS RESULTS, LIGNITE, SAMPLE NO. 73



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10775 EAST 51st AVE., DENVER, COLO. 80239
OFFICE TEL. (303) 373-4772

RADIAN CORPORATION
8500 Shoal Creek Blvd.
Austin, Texas 78758

January 18, 1980

Kind of sample reported to us	Coal
Sample taken at	xxxxx
Sample taken by	Radian Corp.
Date sampled	xxxxx
Date received	1-7-80

Sample identification by

Radian Corp.

Sample No. 73
P.O. No. 32615

Analysis report no. 72-89669

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	6.23	xxxx
% Ash	12.08	12.88
% Volatile	40.54	43.23
% Fixed Carbon	41.15	43.89
	100.00	100.00
Btu	9952	10613
% Sulfur	1.67	1.78

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	6.23	xxxx
% Carbon	58.96	62.88
% Hydrogen	3.97	4.23
% Nitrogen	0.96	1.02
% Chlorine	0.01	0.01
% Sulfur	1.67	1.78
% Ash	12.08	12.88
% Oxygen (diff)	16.12	17.20
	100.00	100.00

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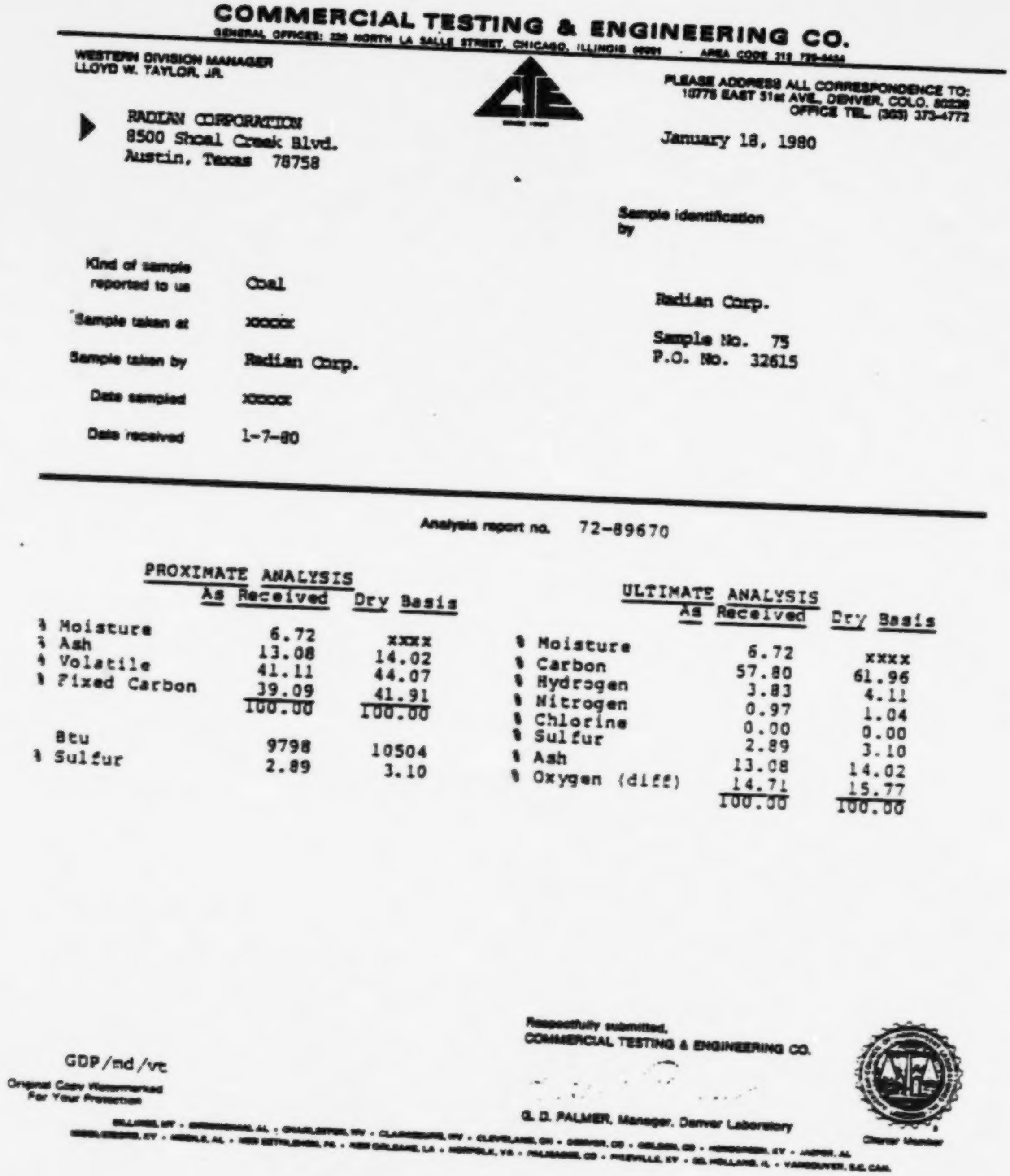
TABLE F-2. PROXIMATE AND ULTIMATE ANALYSIS RESULTS, LIGNITE, SAMPLE NO. 75



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RADIAN CORPORATION
8500 Shoal Creek Blvd.
Austin, Texas 78758

January 18, 1980

Kind of sample reported to us	Coal	Sample identification by	
Sample taken at	XXXXX		Radian Corp.
Sample taken by	Radian Corp.		Sample No. 75 P.O. No. 32615
Date sampled	XXXXX		
Date received	1-7-80		

Analysis report no. 72-89670

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	6.72	xxxx
% Ash	13.08	14.02
% Volatile	41.11	44.07
% Fixed Carbon	39.09	41.91
	100.00	100.00
Btu	9798	10504
% Sulfur	2.89	3.10

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	6.72	xxxx
% Carbon	57.80	61.96
% Hydrogen	3.83	4.11
% Nitrogen	0.97	1.04
% Chlorine	0.00	0.00
% Sulfur	2.89	3.10
% Ash	13.08	14.02
% Oxygen (diff)	14.71	15.77
	100.00	100.00

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TABLE F-3. PROXIMATE AND ULTIMATE ANALYSIS RESULTS, LIGNITE, SAMPLE NO. 76

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RADIAN CORPORATION
8500 Shoal Creek Blvd.
Austin, Texas 78758

January 18, 1980

Kind of sample reported to us	Coal	Sample identification by	Radian Corp.
Sample taken at	xxxxx		Sample No. 76
Sample taken by	Radian Corp.		P.O. No. 32615
Date sampled	xxxxx		
Date received	1-7-80		

Analysis report no. 72-89671

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	6.92	xxxx
% Ash	12.54	13.47
% Volatile	39.55	42.49
% Fixed Carbon	40.99	44.04
	100.00	100.00
Btu	9701	10422
% Sulfur	0.64	0.69

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	6.92	xxxx
% Carbon	58.05	62.37
% Hydrogen	3.97	4.26
% Nitrogen	0.97	1.04
% Chlorine	0.00	0.00
% Sulfur	0.64	0.69
% Ash	12.54	13.47
% Oxygen (diff)	16.91	18.17
	100.00	100.00

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TABLE F-4. PROXIMATE AND ULTIMATE ANALYSIS RESULTS, LIGNITE, SAMPLE NO. 77

F-484

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8500 Shoal Creek Blvd.
Austin, Texas 78758

January 17, 1980

Kind of sample reported to us	Coal
Sample taken at	XXXXX
Sample taken by	Radian Corp.
Date sampled	XXXXX
Date received	1-7-80

Sample identification by

Radian Corp.

Sample No. 77
P.O. No. 32615

Analysis report no. 72-89672

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	5.57	xxxx
% Ash	10.80	11.44
% Volatile	39.16	41.47
% Fixed Carbon	44.47	47.09
	100.00	100.00
Btu	9983	10572
% Sulfur	0.45	0.48

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	5.57	xxxx
% Carbon	59.93	63.47
% Hydrogen	4.06	4.30
% Nitrogen	1.00	1.06
% Chlorine	0.00	0.00
% Sulfur	0.45	0.48
% Ash	10.80	11.44
% Oxygen (diff)	18.19	19.25
	100.00	100.00

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TABLE F-5. PROXIMATE AND ULTIMATE ANALYSIS RESULTS, LIGNITE, SAMPLE NO. 81

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RADIAN CORPORATION
8500 Shoal Creek Blvd.
Austin, Texas 78758

January 17, 1980

Sample identification
by

Radian Corp.

Sample No. 81
P.O. No. 32615

Kind of sample reported to us	Coal
Sample taken at	xxxxx
Sample taken by	Radian Corp.
Date sampled	xxxxx
Date received	1-7-80

Analysis report no. 72-89673

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	5.55	xxxx
% Ash	12.03	12.74
% Volatile	38.34	40.59
% Fixed Carbon	44.08	46.67
	100.00	100.00
Btu	9938	10522
% Sulfur	0.91	0.96

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	5.55	xxxx
% Carbon	59.25	62.73
% Hydrogen	4.01	4.25
% Nitrogen	1.00	1.06
% Chlorine	0.00	0.00
% Sulfur	0.91	0.96
% Ash	12.03	12.74
% Oxygen (diff)	17.25	18.26
	100.00	100.00

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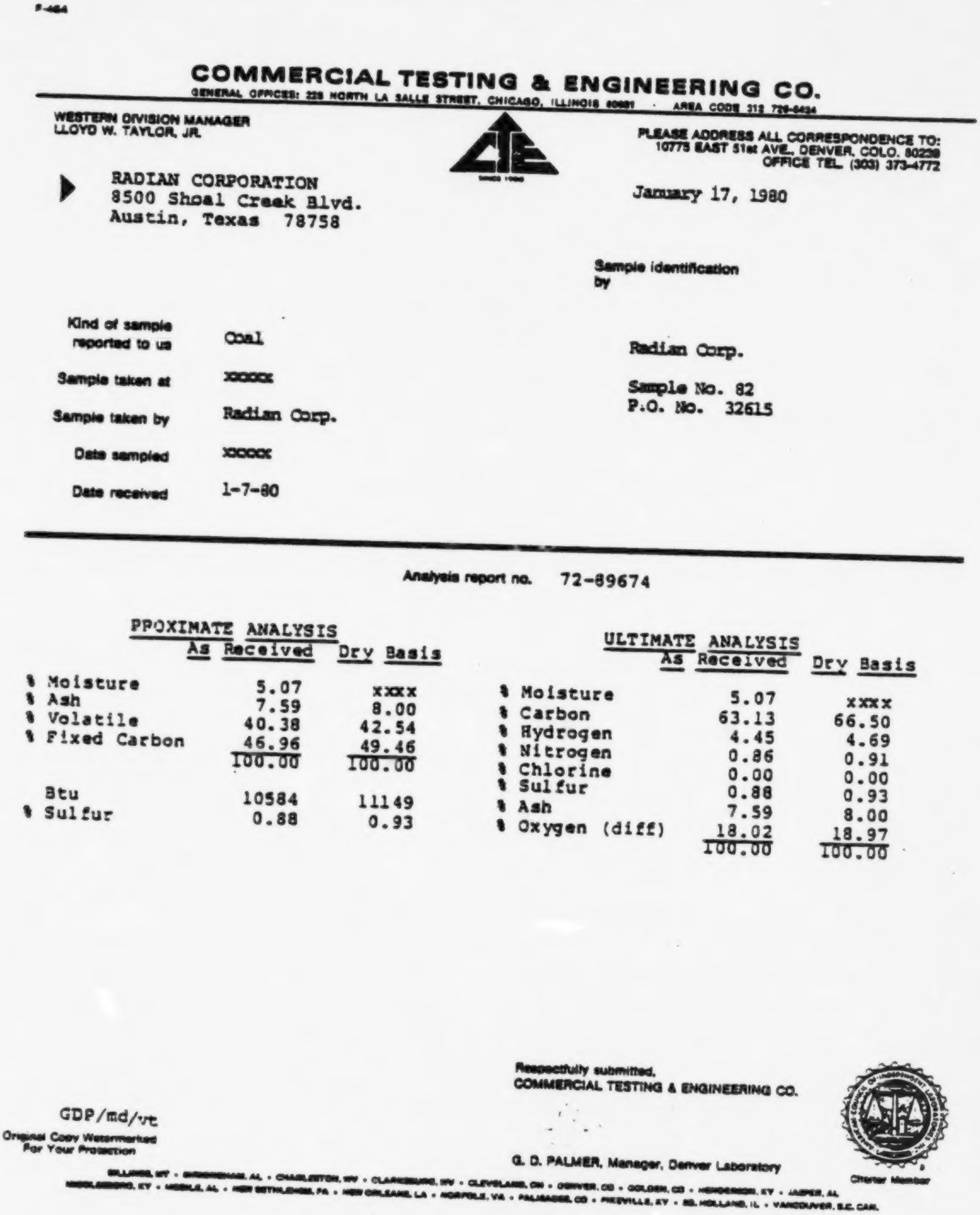
TABLE F-6. PROXIMATE AND ULTIMATE ANALYSIS RESULTS, LIGNITE, SAMPLE NO. 82



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Austin, Texas 78758

January 17, 1980

Kind of sample reported to us	Coal
Sample taken at	xxxxx
Sample taken by	Radian Corp.
Date sampled	xxxxx
Date received	1-7-80

Sample identification by

Radian Corp.

Sample No. 82
P.O. No. 32615

Analysis report no. 72-89674

PROXIMATE ANALYSIS	As Received	Dry Basis
% Moisture	5.07	xxxx
% Ash	7.59	8.00
% Volatile	40.38	42.54
% Fixed Carbon	46.96	49.46
	100.00	100.00
Btu	10584	11149
% Sulfur	0.88	0.93

ULTIMATE ANALYSIS	As Received	Dry Basis
% Moisture	5.07	xxxx
% Carbon	63.13	66.50
% Hydrogen	4.45	4.69
% Nitrogen	0.86	0.91
% Chlorine	0.00	0.00
% Sulfur	0.88	0.93
% Ash	7.59	8.00
% Oxygen (diff)	18.02	18.97
	100.00	100.00

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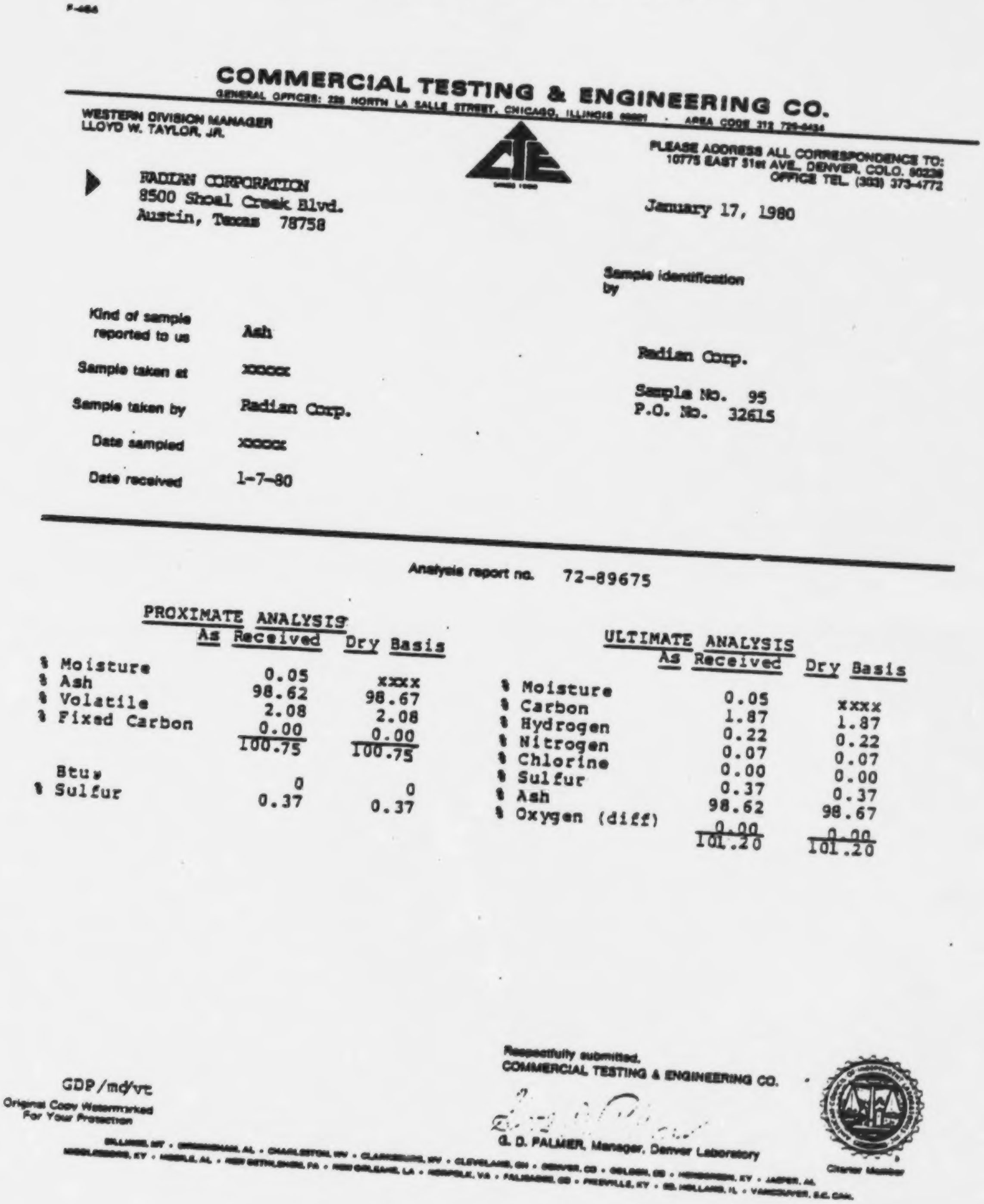
TABLE F-7. PROXIMATE AND ULTIMATE ANALYSIS RESULTS, GASIFIER ASH, SAMPLE NO. 95



F-484

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS [illegible] · AREA CODE 312 [illegible]

WESTERN DIVISION MANAGER
LLOYD W. TAYLOR, JR.

PLEASE ADDRESS ALL CORRESPONDENCE TO:
10775 EAST 51st AVE., DENVER, COLO. 80239
OFFICE TEL. (303) 373-4772

RADIAN CORPORATION
8500 Shoal Creek Blvd.
Austin, Texas 78758

January 17, 1980

Kind of sample reported to us: Ash

Sample taken at: xxxxx

Sample taken by: Radian Corp.

Date sampled: xxxxx

Date received: 1-7-80

Sample identification by

Radian Corp.

Sample No. 95
P.O. No. 32615

Analysis report no. 72-89675

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	0.05	xxxx
% Ash	98.62	98.67
% Volatile	2.08	2.08
% Fixed Carbon	0.00	0.00
	100.75	100.75
Btu	0	0
% Sulfur	0.37	0.37

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	0.05	xxxx
% Carbon	1.87	1.87
% Hydrogen	0.22	0.22
% Nitrogen	0.07	0.07
% Chlorine	0.00	0.00
% Sulfur	0.37	0.37
% Ash	98.62	98.67
% Oxygen (diff)	0.00	0.00
	101.20	101.20

Respectfully submitted,
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TABLE F-8. PROXIMATE AND ULTIMATE ANALYSIS RESULTS, GASIFIER ASH, SAMPLE NO. 98

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10775 EAST 51st AVE., DENVER, COLO. 80239
OFFICE TEL. (303) 373-4772

RADIAN CORPORATION
8500 Shoal Creek Blvd.
Austin, Texas 78758

January 17, 1980

Kind of sample reported to us	Ash	Sample identification by	Radian Corp.
Sample taken at	xxxxx		Sample No. 98
Sample taken by	Radian Corp.		P.O. No. 32615
Date sampled	xxxxx		
Date received	1-7-80		

Analysis report no. 72-89676

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	0.19	xxxx
% Ash	96.18	96.36
% Volatile	4.48	4.49
% Fixed Carbon	0.00	0.00
	100.85	100.85
Btu	57	57
% Sulfur	0.77	0.77

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	0.19	xxxx
% Carbon	4.44	4.45
% Hydrogen	0.14	0.14
% Nitrogen	0.14	0.14
% Chlorine	0.01	0.01
% Sulfur	0.77	0.77
% Ash	96.18	96.36
% Oxygen (diff)	0.00	0.00
	101.87	101.87

Respectfully submitted,
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TABLE F-9. PROXIMATE AND ULTIMATE ANALYSIS RESULTS, GASIFIER ASH, SAMPLE NO. 126

F-464

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OFFICE TEL. (303) 373-4772

RADIAN CORPORATION
8500 Shoal Creek Blvd.
Austin, Texas 78758

January 17, 1980

Sample identification
by

Radian Corp.

Sample No. 126
P.O. No. 32615

Kind of sample reported to us	Ash
Sample taken at	xxxxx
Sample taken by	Radian Corp.
Date sampled	xxxxx
Date received	1-7-80

Analysis report no. 72-89677

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	0.56	xxxx
% Ash	71.89	72.29
% Volatile	9.35	9.40
% Fixed Carbon	18.20	18.31
	100.00	100.00
Btu	3831	3853
% Sulfur	1.53	1.54

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	0.56	xxxx
% Carbon	26.87	27.02
% Hydrogen	0.48	0.48
% Nitrogen	0.41	0.41
% Chlorine	0.01	0.01
% Sulfur	1.53	1.54
% Ash	71.89	72.29
% Oxygen (diff)	0.00	0.00
	101.75	101.75

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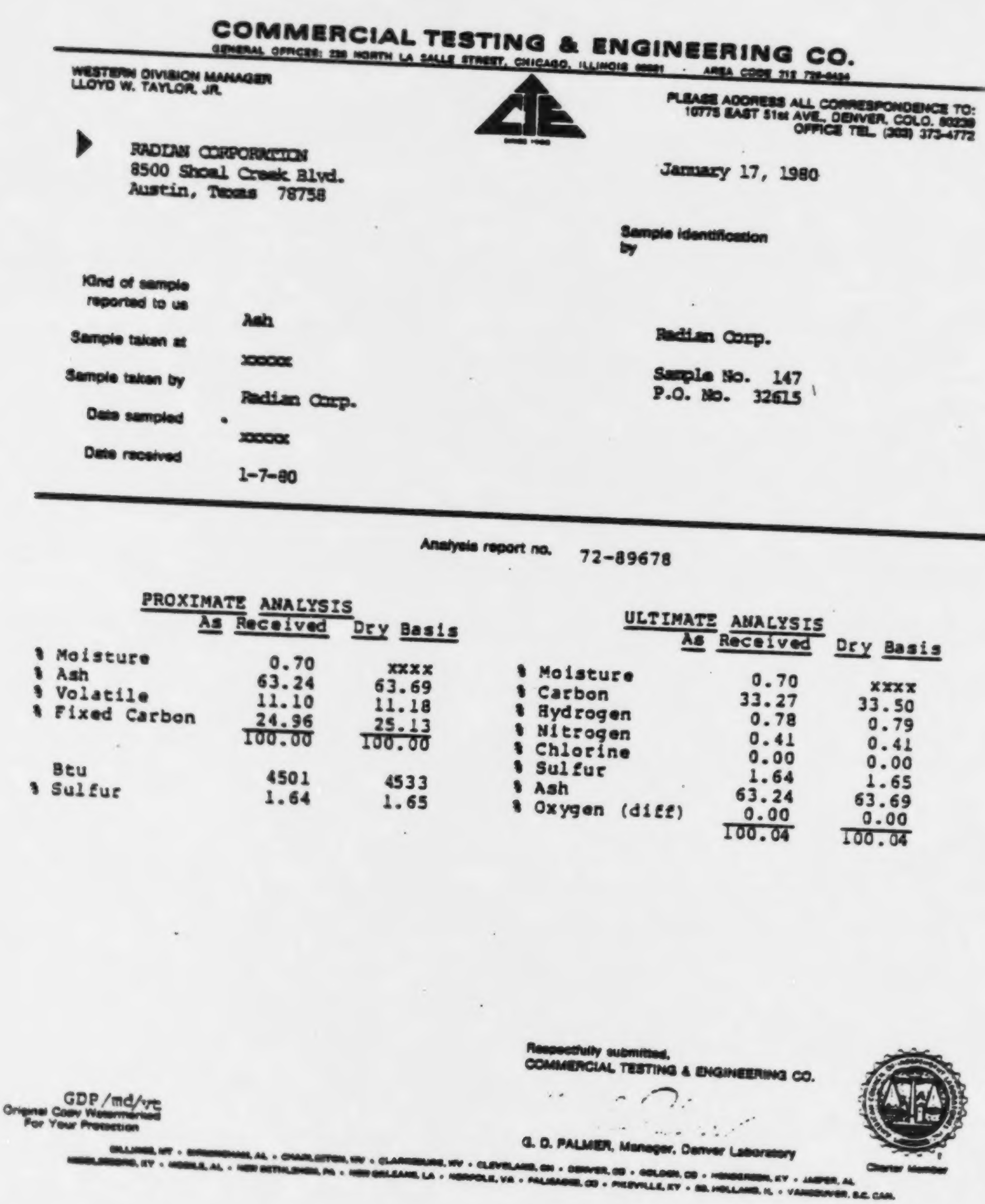
TABLE F-10. PROXIMATE AND ULTIMATE ANALYSIS RESULTS, GASIFIER ASH, SAMPLE NO. 147



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WESTERN DIVISION MANAGER
LLOYD W. TAYLOR, JR.

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OFFICE TEL. (303) 373-4772

RADIAN CORPORATION
8500 Shoal Creek Blvd.
Austin, Texas 78758

January 17, 1980

Kind of sample reported to us	Ash	Sample identification by	
Sample taken at	xxxxx		Radian Corp.
Sample taken by	Radian Corp.		Sample No. 147 P.O. No. 32615
Date sampled	xxxxx		
Date received	1-7-80		

Analysis report no. 72-89678

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	0.70	xxxx
% Ash	63.24	63.69
% Volatile	11.10	11.18
% Fixed Carbon	24.96	25.13
	100.00	100.00
Btu	4501	4533
% Sulfur	1.64	1.65

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	0.70	xxxx
% Carbon	33.27	33.50
% Hydrogen	0.78	0.79
% Nitrogen	0.41	0.41
% Chlorine	0.00	0.00
% Sulfur	1.64	1.65
% Ash	63.24	63.69
% Oxygen (diff)	0.00	0.00
	100.04	100.04

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TABLE F-11. PROXIMATE AND ULTIMATE ANALYSIS RESULTS, GASIFIER ASH, SAMPLE NO. 149

F-484

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WESTERN DIVISION MANAGER
LLOYD W. TAYLOR, JR.

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10775 EAST 51st AVE., DENVER, COLO. 80239
OFFICE TEL. (303) 373-4772

RADIAN CORPORATION
8500 Shoal Creek Blvd.
Austin, Texas 78758

January 17, 1980

Kind of sample reported to us	Ash
Sample taken at	xxxxx
Sample taken by	Radian Corp.
Date sampled	xxxxx
Date received	1-7-80

Sample identification by

Radian Corp.

Sample No. 149
P.O. No. 32615

Analysis report no. 72-89679

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	0.76	xxxx
% Ash	51.24	51.63
% Volatile	11.11	11.20
% Fixed Carbon	36.89	37.17
	100.00	100.00
Btu	6543	6593
% Sulfur	1.71	1.72

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	0.76	xxxx
% Carbon	45.20	45.56
% Hydrogen	0.55	0.55
% Nitrogen	0.55	0.55
% Chlorine	0.00	0.00
% Sulfur	1.71	1.72
% Ash	51.24	51.63
% Oxygen (diff)	0.00	0.00
	100.01	100.01

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TABLE F-12. PROXIMATE AND ULTIMATE ANALYSIS RESULTS, CYCLONE DUST, SAMPLE NO. 153

F-464

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WESTERN DIVISION MANAGER
LLOYD W. TAYLOR, JR.

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10775 EAST 51st AVE., DENVER, COLO. 80239
OFFICE TEL. (303) 373-4772

RADIAN CORPORATION
8500 Shoal Creek Blvd.
Austin, Texas 78758

January 18, 1980

Kind of sample reported to us	Charcoal	Sample identification by	
Sample taken at	xxxxx		Radian Corp.
Sample taken by	Radian Corp.		Sample No. 153 P.O. No. 32615
Date sampled	xxxxx		
Date received	1-7-80		

Analysis report no. 72-89680

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	0.59	xxxx
% Ash	38.21	38.44
% Volatile	14.84	14.93
% Fixed Carbon	46.36	46.63
	100.00	100.00
Btu	8607	8658
% Sulfur	1.59	1.60

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	0.59	xxxx
% Carbon	54.48	54.80
% Hydrogen	1.48	1.49
% Nitrogen	0.83	0.83
% Chlorine	0.00	0.00
% Sulfur	1.59	1.60
% Ash	38.21	38.44
% Oxygen (diff)	2.82	2.84
	100.00	100.00

Respectfully submitted,
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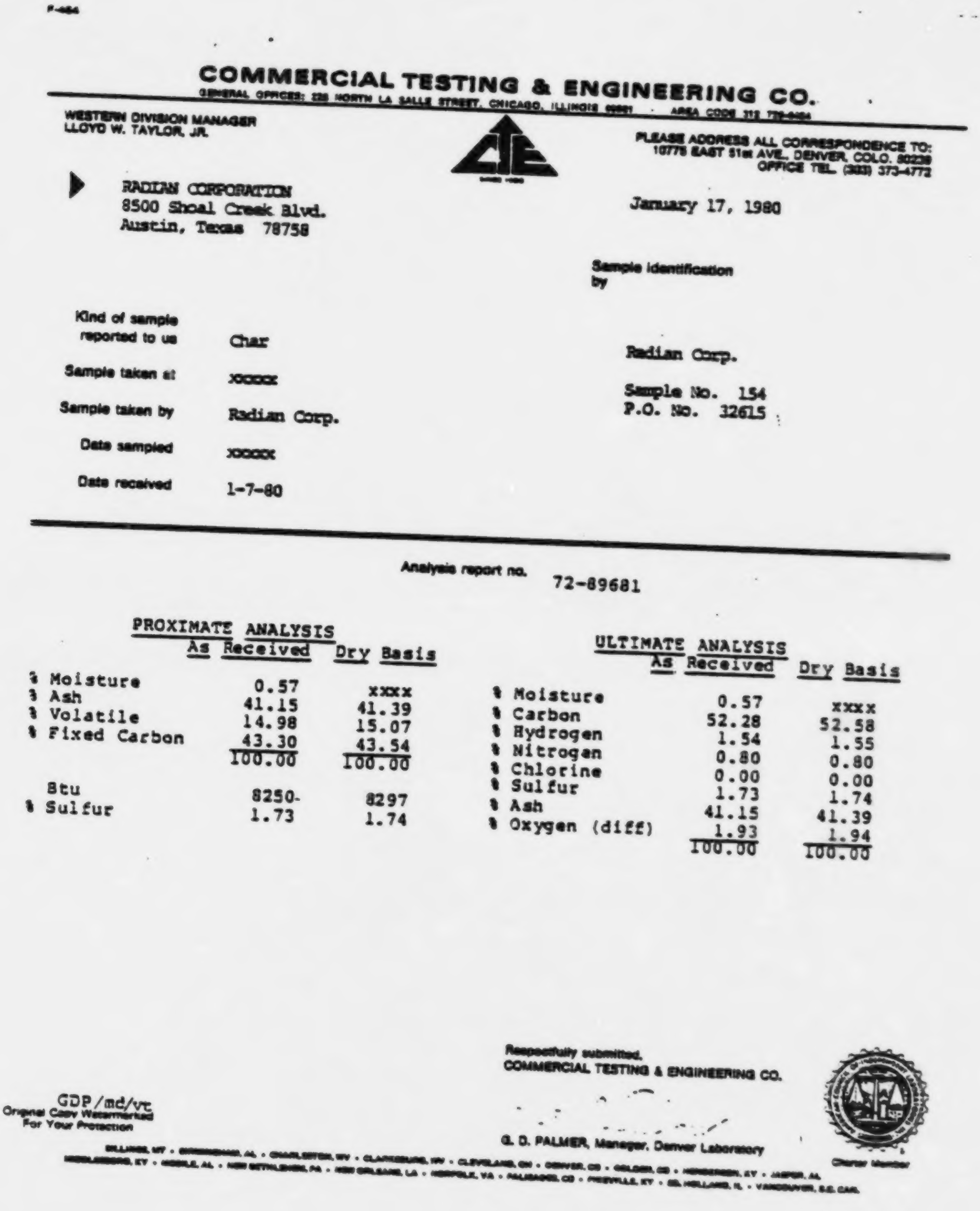
TABLE F-13. PROXIMATE AND ULTIMATE ANALYSIS RESULTS, CYCLONE DUST, SAMPLE NO. 154



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WESTERN DIVISION MANAGER
LLOYD W. TAYLOR, JR.

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OFFICE TEL. (303) 373-4772

RADIAN CORPORATION
8500 Shoal Creek Blvd.
Austin, Texas 78758

January 17, 1980

Kind of sample reported to us	Char	Sample identification by
		Radian Corp.
Sample taken at	xxxxx	Sample No. 154
Sample taken by	Radian Corp.	P.O. No. 32615
Date sampled	xxxxx	
Date received	1-7-80	

Analysis report no. 72-89681

PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	0.57	xxxx
% Ash	41.15	41.39
% Volatile	14.98	15.07
% Fixed Carbon	43.30	43.54
	100.00	100.00
Btu	8250	8297
% Sulfur	1.73	1.74

ULTIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	0.57	xxxx
% Carbon	52.28	52.58
% Hydrogen	1.54	1.55
% Nitrogen	0.80	0.80
% Chlorine	0.00	0.00
% Sulfur	1.73	1.74
% Ash	41.15	41.39
% Oxygen (diff)	1.93	1.94
	100.00	100.00

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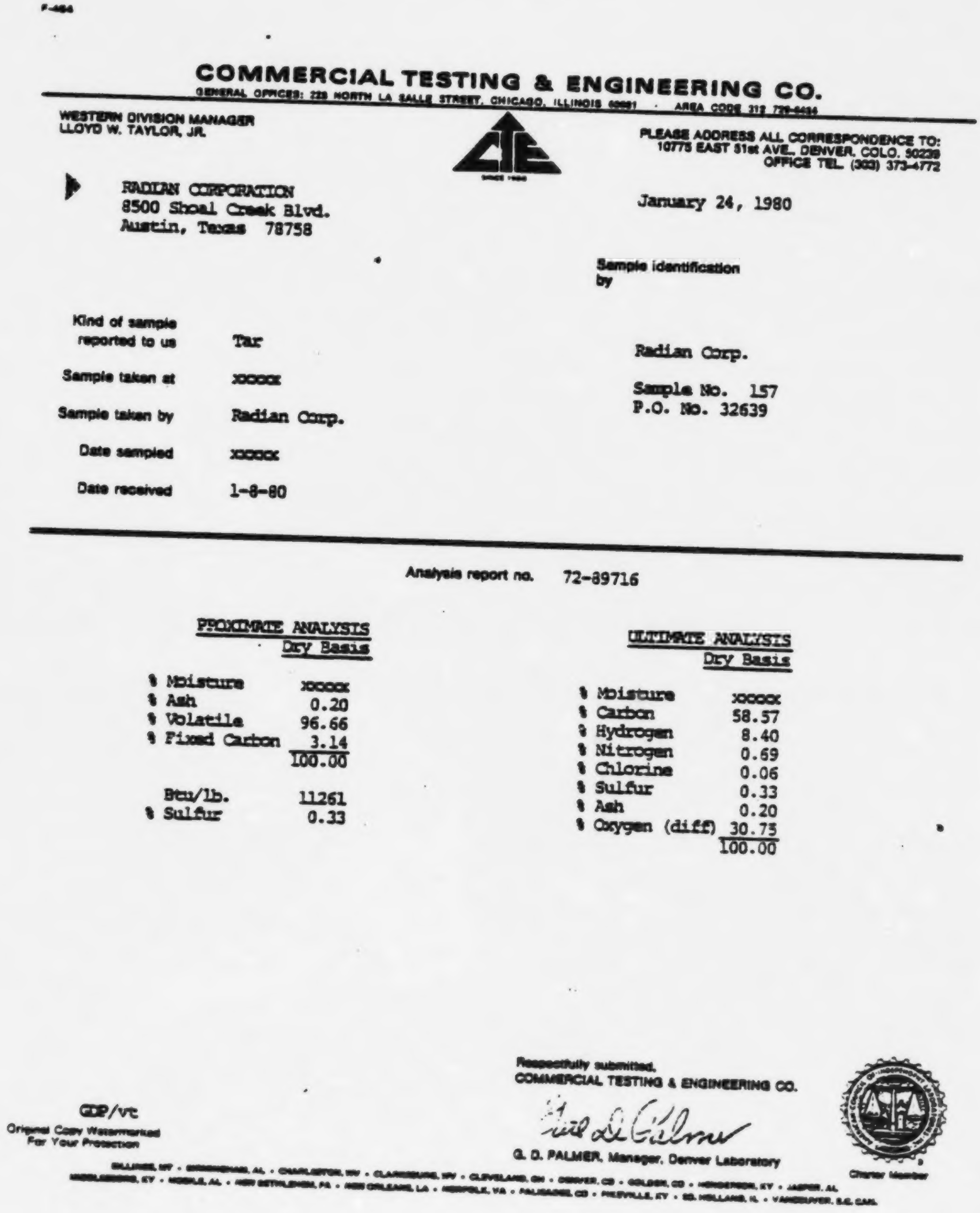
TABLE F-14. PROXIMATE AND ULTIMATE ANALYSIS RESULTS, ESP TAR, SAMPLE NO. 157



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WESTERN DIVISION MANAGER
LLOYD W. TAYLOR, JR.

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10775 EAST 51st AVE., DENVER, COLO. 80239
OFFICE TEL. (303) 373-4772

RADIAN CORPORATION
8500 Shoal Creek Blvd.
Austin, Texas 78758

January 24, 1980

Kind of sample reported to us	Tar
Sample taken at	xxxxx
Sample taken by	Radian Corp.
Date sampled	xxxxx
Date received	1-8-80

Sample identification by

Radian Corp.

Sample No. 157
P.O. No. 32639

Analysis report no. 72-89716

PROXIMATE ANALYSIS

	Dry Basis
% Moisture	xxxxx
% Ash	0.20
% Volatile	96.66
% Fixed Carbon	3.14
	100.00
Btu/lb.	11261
% Sulfur	0.33

ULTIMATE ANALYSIS

	Dry Basis
% Moisture	xxxxx
% Carbon	58.57
% Hydrogen	8.40
% Nitrogen	0.69
% Chlorine	0.06
% Sulfur	0.33
% Ash	0.20
% Oxygen (diff)	30.75
	100.00

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COMMERCIAL TESTING & ENGINEERING CO.

G. D. PALMER, Manager, Denver Laboratory

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TABLE F-15. LIGNITE SULFUR ANALYSIS

Sample No.	Delivery Time (hrs)	Sulfur Concentration (%)	Approx. Time Fed to Gasifier (hrs)
RM-66	12/12 1100	0.66	
RM-67	1245	0.75	
RM-68	1345	1.39	
RM-70*	2245	1.03	12/13 1130
RM-71*	2300	0.62	1300
RM-72*	2350	0.88	1415
RM-73*	12/13 0700	1.78	1530
RM-74*	0900	0.95	1650
RM-75*	1100	3.10	1930
RM-76*	1215	0.69	2050
RM-132*	1315	1.14	2210
RM-77*	1415	0.48	2330
RM-133*	1515	0.91	12/14 0050
RM-78*	1630	0.49	0210
RM-134*	1730	0.54	0330
RM-79*	1800	0.80	0450
RM-81*	1945	0.96	0600
RM-82*	2045	0.93	0720
RM-135*	2230	0.37	0845
RM-83*	2345	2.99	1000
		Avg = 1.10*	
RM-136	12/14 0600	0.82	1120

* Used for determination of average sulfur content of lignite for material balance.

F.1.2 Particle Size Distribution

TABLE F-16. AVERAGE SIZE DISTRIBUTION FOR SIX SAMPLES (NUMBERS 73, 75, 76, 77, 81 AND 82) OF LIGNITE FEEDSTOCK

Retained on (Aperture Size, mm)	Weight Percent Coarser Than This Aperture, Average for 6 Samples
50.8	0
44.4	6.66
38.1	15.9
25.4	55.5
12.7	86.0
9.52	94.3
6.35	98.4
(Remainder)	100

TABLE F-17. LIGNITE FEEDSTOCK PARTICLE SIZE DISTRIBUTION

Sample Number	Retained on (Aperture Size, mm)	Fraction Weight	Percent of Total	Percent Coarser than this Aperture
73	50.8	0.00	0	0
	44.4	56.21	6.35	6.35
	38.1	169.73	19.2	25.5
	25.4	340.38	38.5	64.0
	12.7	174.95	19.8	83.8
	9.52	67.05	7.58	91.4
	(Remainder)	76.50	8.65	100
	Total	884.82		
75	50.8	0.00	0	0
	44.4	20.60	2.45	2.45
	38.1	150.73	17.9	20.4
	25.4	390.89	46.5	66.9
	12.7	164.22	19.5	86.5
	9.52	76.94	9.16	95.6
	6.35	27.27	3.25	98.9
	(Remainder)	9.49	1.13	100
	Total	840.14		
76	50.8	0.00	0	0
	44.4	46.99	6.25	6.25
	38.1	62.75	8.35	14.6
	25.4	402.99	53.6	68.2
	12.7	149.94	19.9	88.2
	9.52	57.74	7.68	95.8
	6.35	18.81	2.50	98.3
	(Remainder)	12.53	1.67	100
	Total	751.75		

(Continued)

TABLE F-17. Continued

Sample Number	Retained on (Aperture Size, mm)	Fraction Weight	Percent of Total	Percent Coarser than this Aperture
77	50.8	0	0	0
	44.4	0	0	0
	38.1	31.23	4.46	4.46
	25.4	275.83	39.4	43.8
	12.7	318.90	45.5	89.4
	9.52	50.42	7.20	96.6
	6.35	14.32	2.04	98.6
	(Remainder)	9.80	1.40	100
	Total	700.50		
81	50.8	0	0	0
	44.4	0	0	0
	38.1	38.82	4.35	4.35
	25.4	293.53	31.8	36.1
	12.7	412.83	46.2	82.3
	9.52	90.16	10.1	92.4
	6.35	42.72	4.79	98.4
	(Remainder)	14.72	1.65	100
	Total	892.78		
82	50.8	0	0	0
	44.4	83.81	11.6	11.6
	38.1	103.68	14.4	26.0
	25.4	201.58	27.9	53.9
	12.7	228.73	31.7	85.6
	9.52	60.97	8.45	94.1
	6.35	28.39	3.93	98.0
	(Remainder)	14.55	2.02	100
	Total	721.71		

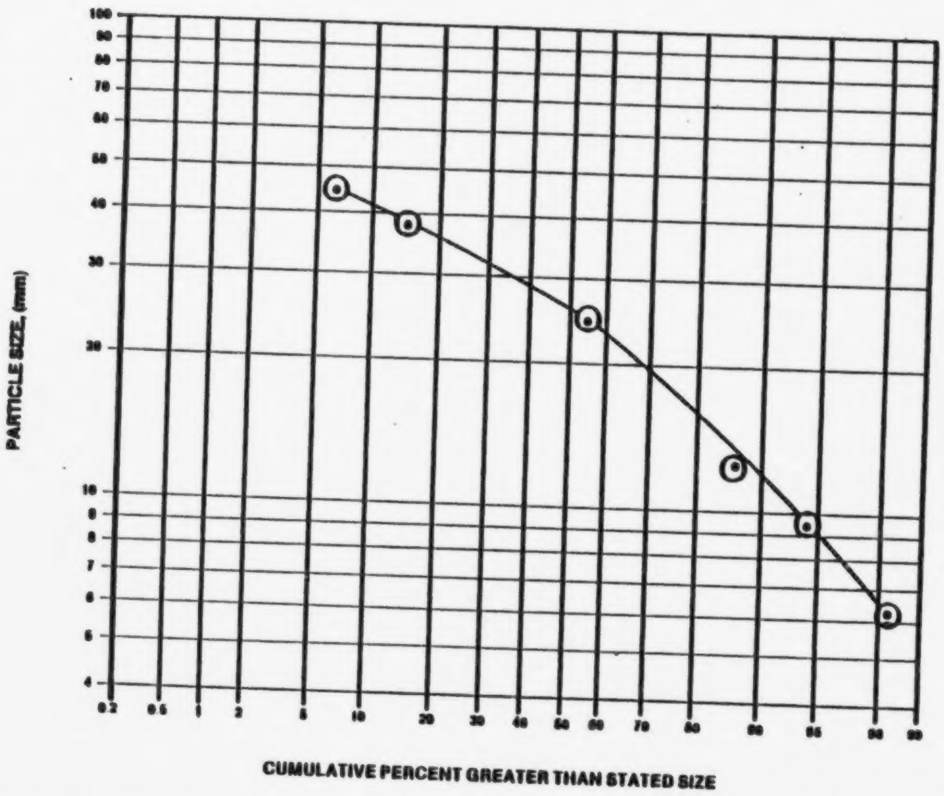

Figure F-1. Average Particle Size Distribution for Six Lignite Samples (Numbers 73, 75, 76, 77, 81 and 82)

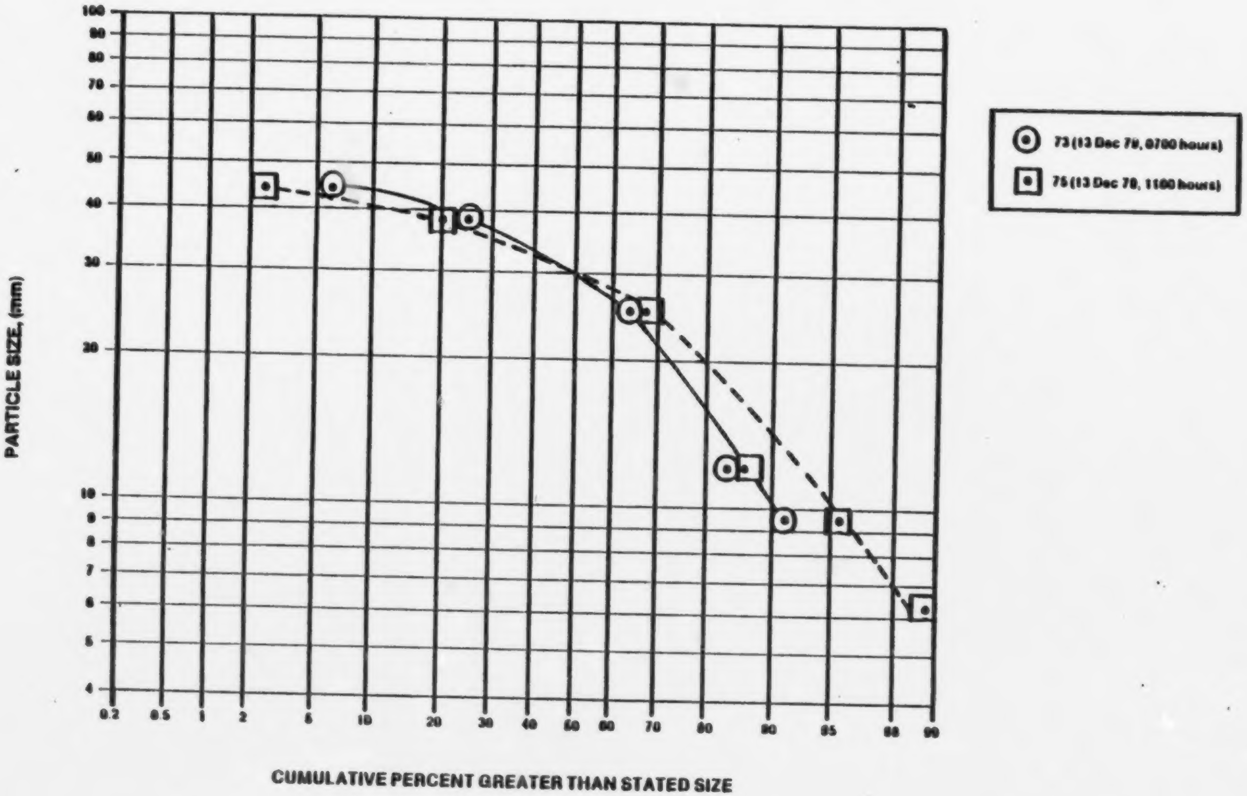

Figure F-2. Lignite Particle Size Distribution -- Samples 73 and 75

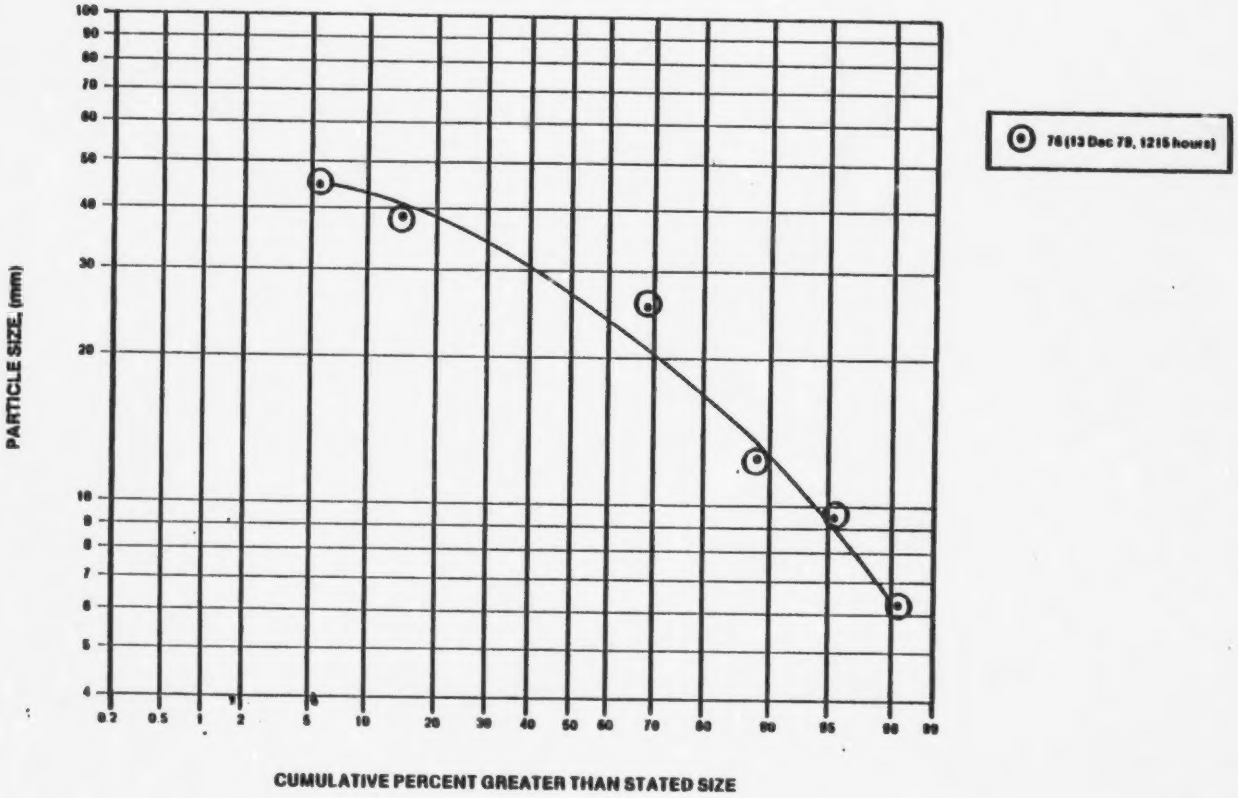

Figure F-3. Lignite Particle Size Distribution -- Sample 76

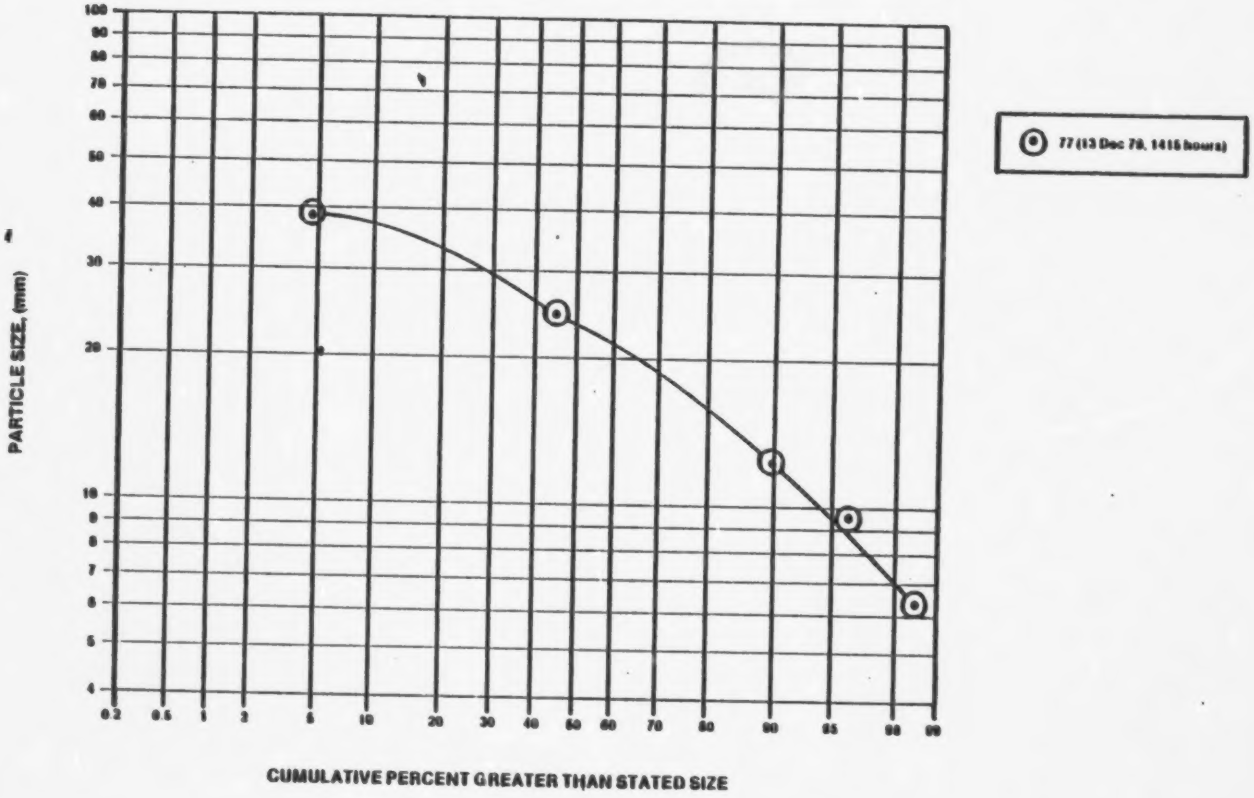

Figure F-4. Lignite Particle Size Distribution -- Sample 77

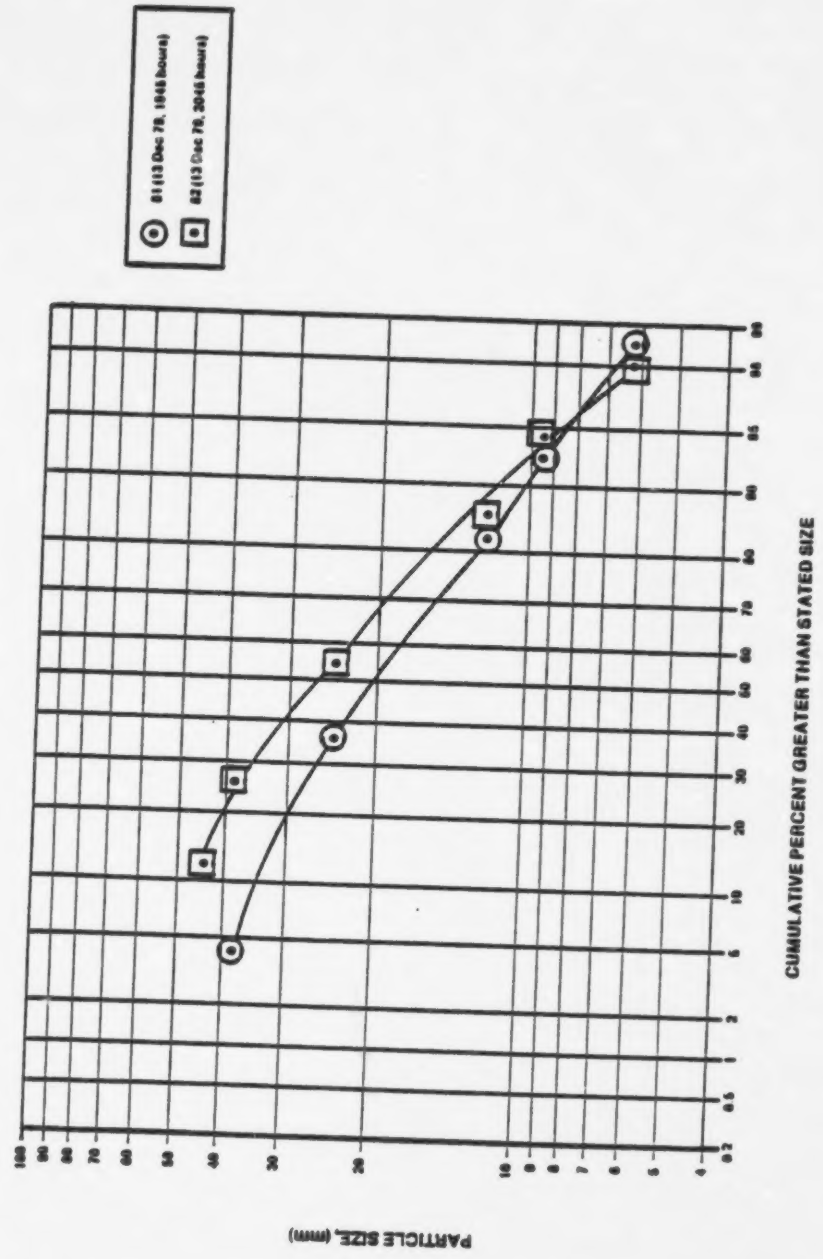

Figure F-5. Lignite Particle Size Distribution -- Samples 81 and 82

TABLE F-18. AVERAGE SIZE DISTRIBUTION FOR FIVE SAMPLES (NUMBERS 95, 98, 126, 147, AND 149) OF GASIFIER ASH

Retained on (Aperture Size, mm)	Weight Percent Coarser Than This Aperture, Average for 6 Samples
12.5	23.9
9.5	38.5
6.3	45.8
2.0	72.6
1.0	86.3
.710	90.0
(Remainder)	100

TABLE F-19. GASIFIER ASH PARTICLE SIZE DISTRIBUTION

Sample Number	Retained on (Aperture Size, mm)	Fraction Weight	Percent of Total	Percent Coarser than this Aperture
95	12.5	83.51	29.5	29.5
	9.5	82.42	29.1	58.6
	6.3	52.28	18.5	77.0
	2.0	36.73	13.0	90.0
	1.0	10.39	3.67	93.7
	.710	2.77	1.00	94.7
	(Remainder)	15.13	5.34	100
	Total	283.23		
98	12.5	110.29	33.3	33.3
	9.5	55.92	16.9	50.2
	6.3	49.41	14.9	65.1
	2.0	61.94	18.7	83.8
	1.0	24.69	7.45	91.2
	.710	7.96	2.40	93.6
	(Remainder)	21.08	6.36	100
	Total	331.29		
126	12.5	27.73	8.90	8.90
	9.5	21.96	7.05	15.9
	6.3	40.80	13.1	29.0
	2.0	111.64	35.8	64.9
	1.0	53.54	17.2	82.0
	.710	15.20	4.88	86.9
	(Remainder)	40.79	13.1	100
	Total	311.66		
147	9.5	55.86	29.2	29.2
	6.3	16.65	8.69	37.9
	2.0	61.57	32.1	70.0
	1.0	30.87	16.1	86.1
	.710	7.19	3.75	89.9
	(Remainder)	19.42	10.1	100
	Total	191.56		
149	6.3	42.96	20.1	20.1
	2.0	73.13	34.2	54.2
	1.0	51.52	24.1	78.3
	.710	14.43	6.74	85.1
	(Remainder)	31.97	14.9	100
	Total	214.01		

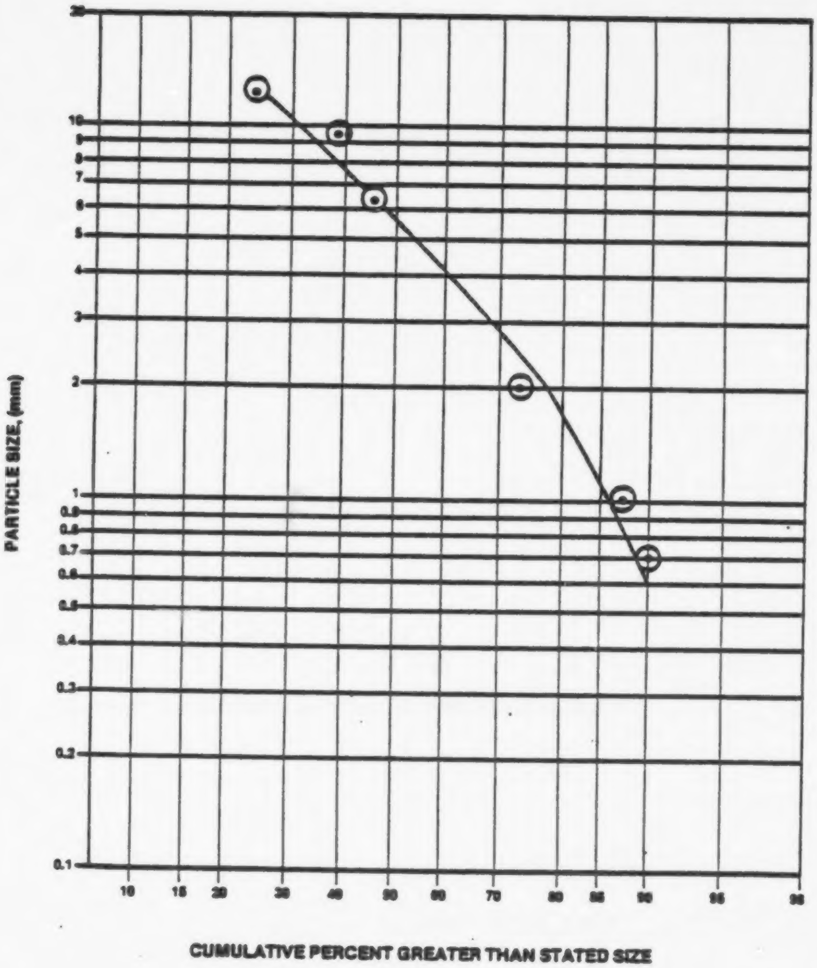

Figure F-6. Average Particle Size Distribution for Five Gasifier Ash Samples (Numbers 95, 98, 126, 147 and 149)

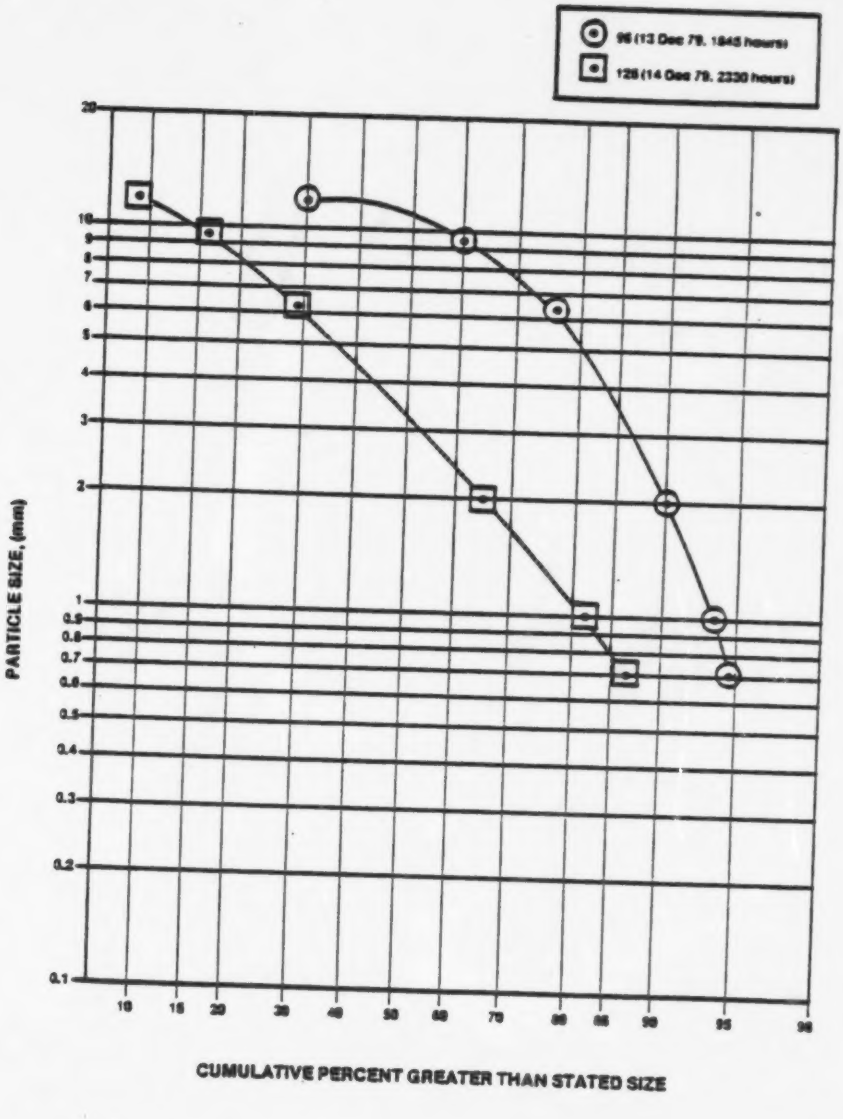

Figure F-7. Gasifier Ash Particle Size Distribution -- Samples 95 and 126

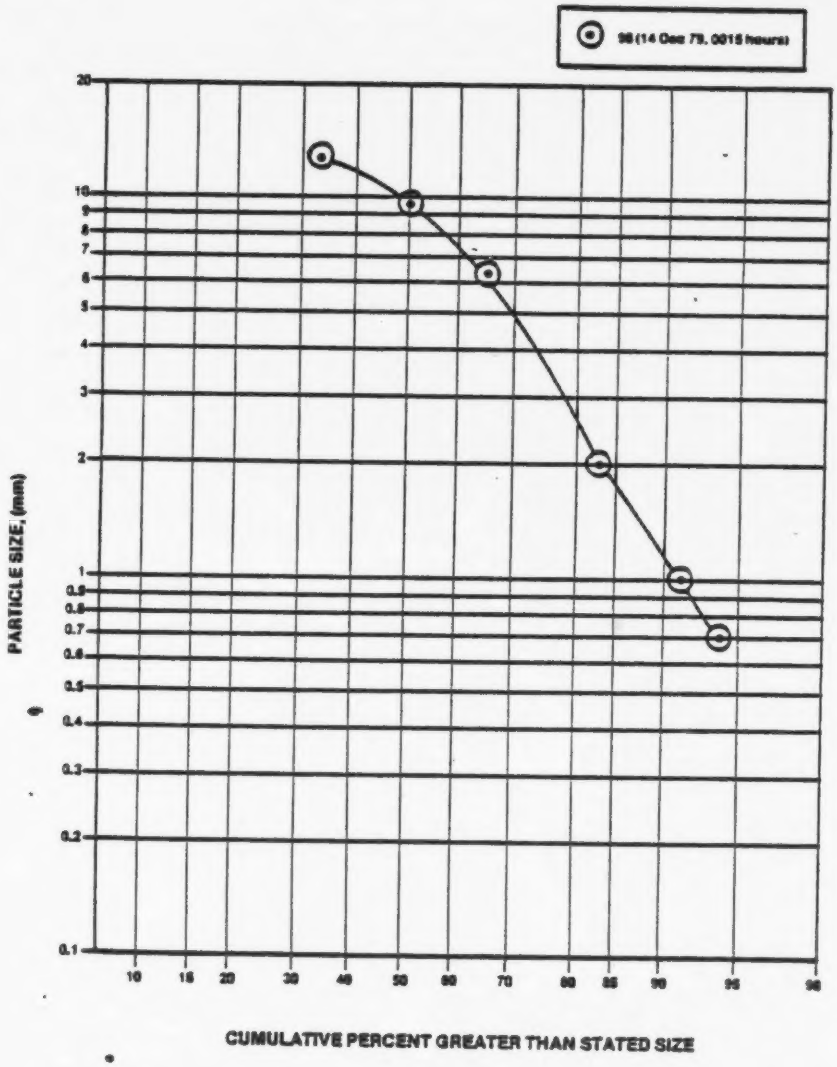

Figure F-8. Gasifier Ash Particle Size Distribution -- Sample 98

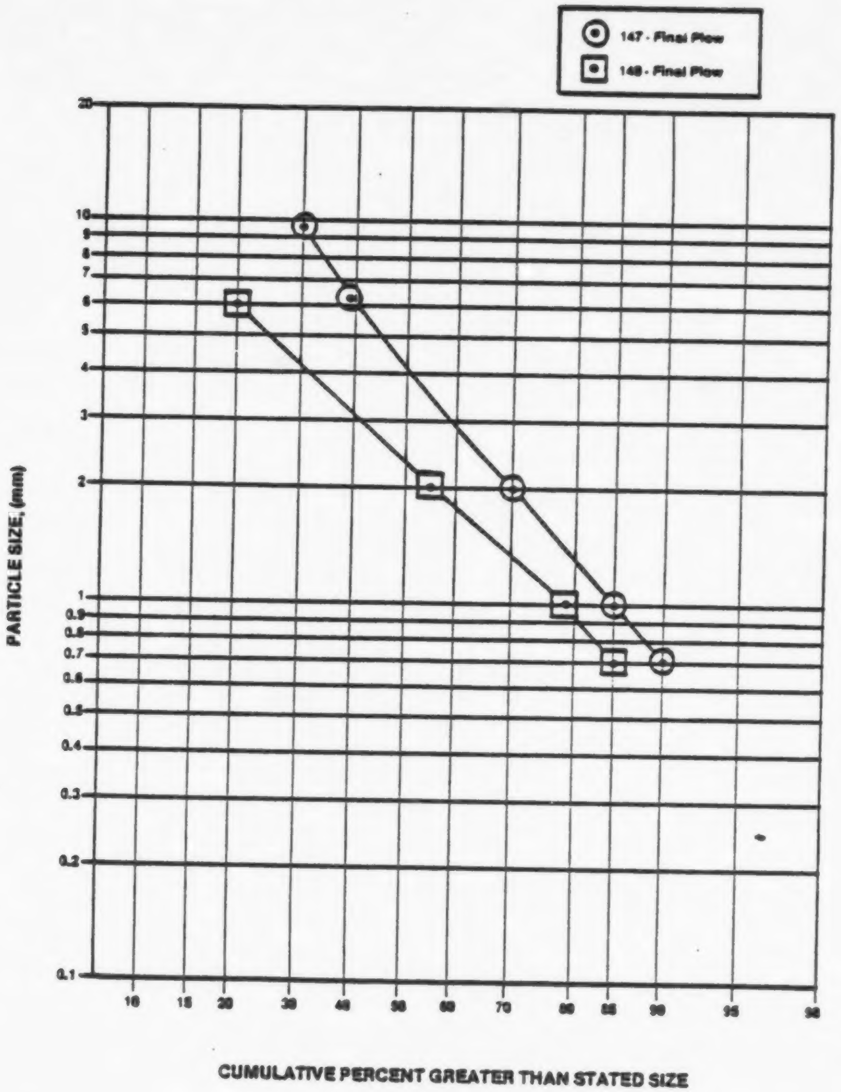

Figure F-9. Gasifier Ash Particle Size Distribution — Samples 147 and 149

TABLE F-20. AVERAGE SIZE DISTRIBUTION FOR TWO SAMPLES (NUMBERS 153 AND 154) OF CYCLONE DUST

Retained on (Aperture Size, mm)	Weight Percent Coarser Than This Aperture, Average for 2 Samples
1.00	.758
.71	3.24
.25	37.4
.125	65.7
.063	88.5
(Remainder)	100

TABLE F-21. CYCLONE DUST PARTICLE SIZE DISTRIBUTION

Sample Number	Retained on (Aperture Size, mm)	Fraction Weight	Percent of Total	Percent Coarser than this Fraction
153	1.00	1.05	0.655	0.655
	.710	3.30	2.06	2.71
	.25	50.53	31.5	34.3
	.125	46.58	29.1	63.3
	.063	37.31	23.3	86.6
	(Remainder)	21.46	13.4	100
	Total	160.23		
154	1.00	1.66	0.862	0.862
	.710	5.58	3.76	3.76
	.25	70.82	36.8	40.5
	.125	53.02	27.5	68.1
	.063	42.88	22.3	90.4
	(Remainder)	18.55	9.64	100
	Total	192.51		

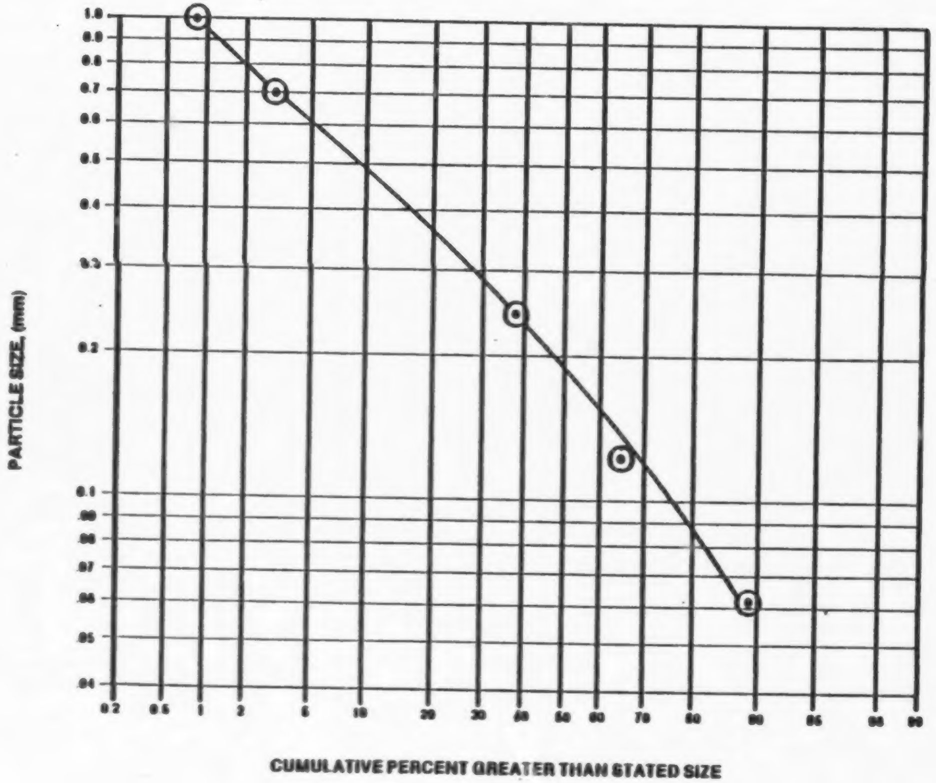

Figure F-10. Average Particle Size Distribution for Two Cyclone Dust Samples (Numbers 153 and 154)

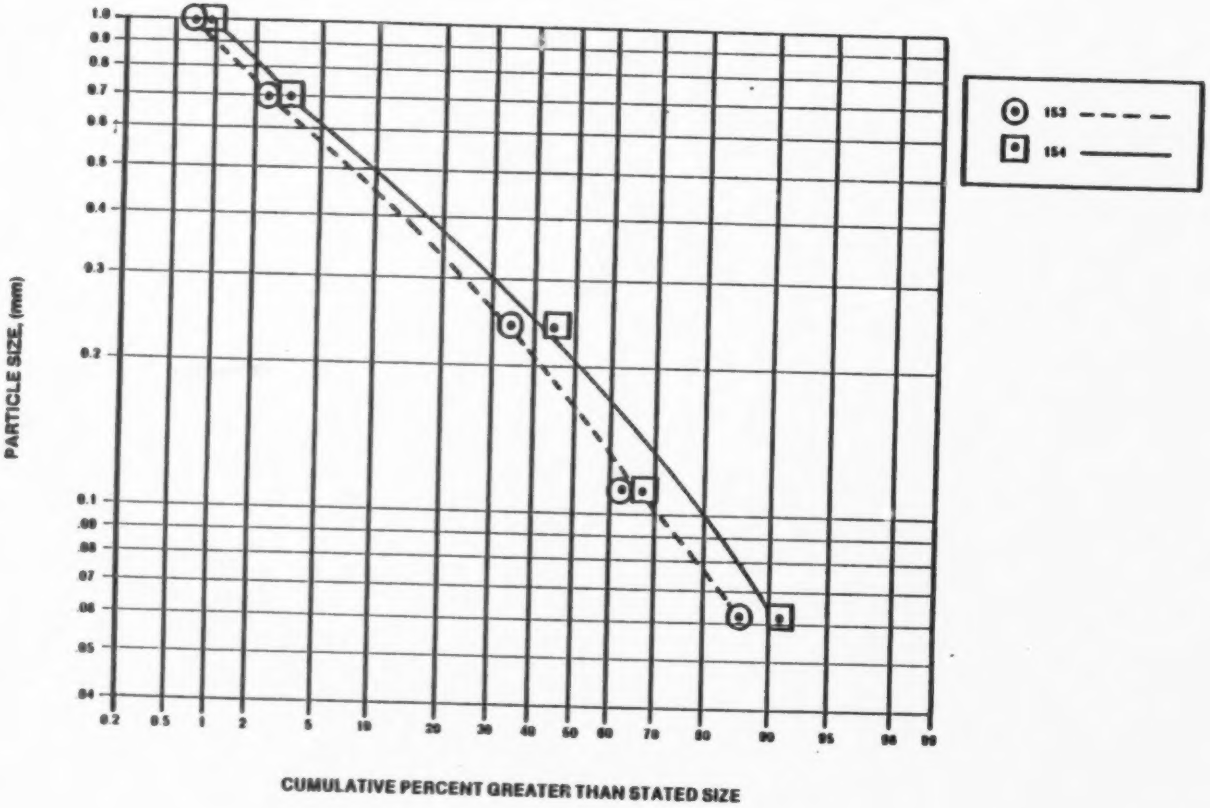

Figure F-11. Cyclone Dust Particle Size Distribution — Samples 153 and 154

F.1.3 Lignite Moisture Content

TABLE F-22. LIGNITE MOISTURE ANALYSIS

Sample Number	Date	Time	% Moisture
RM-73	12/13	0700	32.7
RM-75	12/13	1100	31.4
RM-76	12/13	1215	32.6
RM-77	12/13	1415	34.1
RM-81	12/13	1945	32.6
RM-82	12/13	2045	33.3
			Average = 32.8

F.1.4 Radioactivity Results

TABLE F-23. SPECIFIC ISOTOPE ANALYSIS

Nuclide	Lignite (RM-73)			Lignite (RM-77)			Gasifier Ash			Cyclone Dust		
	Activity p/Ci/g	Precision 2σ(%)	Counting System	Activity p/Ci/g	Precision 2σ(%)	Counting System	Activity p/Ci/g	Precision 2σ(%)	Counting System	Activity p/Ci/g	Precision 2σ(%)	Counting System
PO-210	0.100	43.00	AS14	0.1710	36.84	AS15	0.4040	18.56	AS03	1.0180	22.10	AS2
RA-226	0.200	4.00	LC	0.300	3.00	LC	2.700	3.00	LC	3.700	1.00	LC
U-234	0.1806	11.28	AS10	0.2165	11.57	AS11	1.1830	11.23	AS9	0.8399	12.30	AS12
U-235	0.02748	22.97	AS10	0.01298	27.03	AS11	0.06153	31.12	AS9	0.09286	21.66	AS12
U-238	0.1965	11.07	AS10	0.2093	11.63	AS11	1.3220	11.01	GEL2	0.8631	12.26	AS12
K-40	1.70	34.00	GEL2	0.5800	37.00	GEL2	7.800	17.00	GEL2	6.8000	22.00	GEL2
Pb-214	0.350	40.00	GEL2				1.700	42.00	GEL2	1.5000	28.00	GEL2
Bi-214	0.760	41.00	GEL2				1.200	22.00	GEL2	1.3000	23.00	GEL2
Th-233	0.730	51.00	GEL2				0.7300	27.00	GEL2	0.8000	31.00	GEL2
Th-227	0.0368	26.06	AS5	0.03138	25.11	AS6	0.1684	29.10	AS1	0.1146	25.89	AS2
Th-228	0.1906	12.34	AS5	0.1167	13.06	AS6	1.1410	12.09	AS1	0.6016	12.26	AS2
Th-230	0.1743	11.94	AS5	0.2077	10.73	AS6	1.4820	10.92	AS1	0.8474	10.98	AS2
Th-232	0.1679	12.05	AS5	0.1075	12.35	AS6	1.0960	11.58	AS1	0.5685	11.80	AS2
Pb-210	2.6690	149.46	SB2A	0.4620	685.68	(SB7B)	0.5560	102.52	ABET	0.9660	108.90	SB2A

CDM
environmental engineers, scientists, planners, & management consultants

TABLE F-24. GROSS ALPHA AND BETA RADIATION

CAMP DRESSER & McKEE INC.

11455 West 48th Avenue
Wheat Ridge, Colorado 80033
303 422-0469

May 12, 1980

Mr. David Hayes
Radian Corporation
P.O. Box 9948
Austin, TX 78766

RE: 185-9843-4
P.O. #33991

REPORT OF ANALYSIS

Lab Designation Sponsor Designation	185-9843-4-1 4566 Lignite	185-9843-4-2 4567 Lignite	185-9843-4-3 4568 Cyclone Dust	185-9843-4-4 4658 Gasifier Ash
Determination (pCi/g)				
Gross Alpha ± Counting Error*	2.2 ± 3.3	0.6 ± 2.6	17 ± 7	25 ± 8
Gross Beta ± Counting Error*	2 ± 16	6 ± 15	0 ± 15	18 ± 16

*Variability of the radioactive disintegration process (counting error) at the 95% confidence level, 1.96σ.

Reported on air dry basis.

BY

for Nancy Ebbesen
Radiochemistry
Assistant Supervisor

NE/rjf

F.1.5 Trace Element Analyses

F.1.5.1 Elemental Concentrations in Effluent Streams and Leachates of Gasifier Ash and Cyclone Dust

TABLE F-25. ELEMENTAL CONCENTRATIONS[1] IN PRODUCT GAS AEROSOLS[2]

	Tar Fraction[2]					
	Probe	ESP	Filter	Weighted Average[3]	Particulate Fraction	Composite[5.3]
Aluminum	2.3 E1	1.2 E1	2.1 E1	1.3 E1	>1.0 E3	>1.4 E2
Antimony	<1.1	2.7	<1.0	2.5	7.1 E1	1.1 E1
Arsenic	5.7 E1	6.0 E1	6.8 E1*	6.0 E1	>1.0 E3	>1.8 E2
Barium	1.1 E2	LB	LB	4.3	>1.0 E3	>1.3 E2
Beryllium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	2.0 E-1	<3.3 E-1[4]
Bismuth	<1.1	<3.0 E-1	<1.0	<3.5 E-1	7.0	<1.2[4]
Boron	1.1 E2	1.2 E1	1.0 E2	1.8 E1	8.5 E1	2.7 E1
Bromine	1.0 E1	2.4	1.7	2.7	3.0	2.7
Cadmium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	7.0	<1.2[4]
Calcium	4.2 E2	1.6 E2	2.2 E2	1.7 E2	>1.0 E3	>2.8 E2
Carbon	NR	NR	NR	NR	NR	NR
Cerium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	7.1 E1	9.1
Cesium	<1.1	6.0 E-1	<1.0	<6.3 E-1[4]	3.3 E1	<4.8
Chlorine	3.4 E1	6.0	1.0 E1	7.2	5.1 E2	7.2 E1
Chromium	1.7 E1	9.1 E-1	6.8	1.7	6.9 E2	9.0 E1
Cobalt	≤5.7 E-1	≤3.0	≤1.0	≤2.9	2.0	≤2.8[4]
Copper	5.5	1.2 E1	1.7 E1	1.2 E1	1.2 E2	2.6 E1
Dysprosium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	4.0	<8.2 E-1[4]
Erbium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	8.0 E-1	<4.1 E-1[4]
Europium	<1.1	<3.0 E1	<1.0	<3.5 E-1	1.0	<4.3 E-1[4]
Fluorine	~5.0 E1	~5.0 E1	~5.4 E1	~5.1 E1	~8.0 E2	~1.3 E2
Gadolinium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	4.0	<8.2 E-1[4]
Gallium	5.1 E1	1.2	3.1 E1*	3.8	3.0 E1	7.2
Germanium	<1.1	1.8	<1.0	1.7	9.1 E1	1.3 E1
Gold	<1.1	<3.0 E-1	<1.0	<3.5 E-1	<1.0 E-1	<3.2 E-1
Hafnium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	<2.0	<5.6 E-1[4]
Holmium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	3.0	<6.9 E-1[4]
Hydrogen	NR	NR	NR	NR	NR	NR
Indium	NR	NR	NR	NR	NR	NR
Iodine	<1.1	6.0 E-1	<1.0	<6.3 E-1[4]	9.0	<1.7[4]
Iridium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	<1.0 E-1	<3.2 E-1
Iron	LB	LB	LB	LB	>1.0 E3	>1.3 E2
Lanthanum	<1.1	<3.0 E-1	<1.0	<3.5 E-1	9.4 E1	1.2 E1
Lead	1.0 E1	5.4	≤3.4	5.5	7.4 E2	1.0 E2
Lithium	2.8	1.2*	1.7	1.3	6.0	1.9
Lutetium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	≤9.0 E-1	<4.2 E-1
Magnesium	1.2 E2	6.0	4.1 E1	1.1 E1	>1.0 E3	>1.4 E2
Manganese	4.5 E-1	5.4 E-1	1.3	5.5 E-1	1.8 E2	2.4 E1
Mercury	NR	NR	NR	NR	NR	NR
Molybdenum	3.9 E1*	2.4	9.6	4.0	8.1 E1	1.4 E1

(Continued)

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TABLE F-25. Continued

	Tar Fraction[1]					
	Probe	ESP	Filter	Weighted Average[3]	Particulate Fraction	Composite[5,3]
Neodymium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	1.0 E1	<1.6[4]
Nickel	1.1 E1	2.3	6.7	2.7	9.4 E1	1.4 E1
Niobium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	2.1 E1	<3.0[4]
Nitrogen	NR	NR	NR	NR	NR	NR
Osmium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	<1.0 E-1	<3.2 E-1
Oxygen	NR	NR	NR	NR	NR	NR
Palladium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	<1.0 E-1	<3.2 E-1
Phosphorous	2.4 E1	2.2 E1	4.1 ~	2.2 E1	>1.0 E3	>1.5 E2
Platinum	<1.1	<3.0 E-1	<1.0	<3.5 E-1	<1.0 E-1	<3.2 E-1
Potassium	2.0 E2	1.7 E2	2.2 E2	1.7 E2	>1.0 E3	>2.8 E2
Praseodymium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	5.0	<9.5 E-1
Rhenium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	<1.0 E-1	<3.2 E-1
Rhodium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	<1.0 E-1	<3.2 E-1
Rubidium	5.7 E-1	3.0 E-1	3.4 E-1	3.1 E-1	7.9 E1	1.0 E1
Ruthenium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	<1.0 E-1	<3.2 E-1
Samarium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	8.0	<1.3[4]
Scandium	≤5.7 E-1	≤3.0 E-1	≤3.4 E-1	≤3.1 E-1	2.0	<5.3 E-1[4]
Selenium	<1.1	≤9.2 E-1	<1.0	<9.2 E-1	5.0	<1.4[4]
Silicon	>2.8 E3	>6.0 E2	8.2 E2	>6.9 E2	>1.0 E3	>7.3 E2
Silver	<1.1	6.0*	<1.0	5.6	3.8 E1	9.8
Sodium	1.4 E2	>6.0 E2	3.5 E2	>5.8 E2	>1.0 E3	>6.3 E2
Strontium	4.0	2.1	1.4	2.2	>1.0 E3	>1.3 E2
Sulfur	1.1 E1	1.9 E2	LB	1.8 E2	>1.0 E3	>2.9 E2
Tantalum	<1.1	<3.0 E-1	1.0 E1*	<3.5 E-1	≤2.0	<5.6 E-1
Tellurium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	<1.0 E-1	<3.2 E-1
Terbium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	2.0	<5.6 E-1[4]
Thallium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	4.0	<8.2 E-1[4]
Thorium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	1.7 E1	<2.5
Thulium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	1.0 E-1	<3.2 E-1[4]
Tin	<1.1	≤6.0 E-1	<1.0	<6.3 E-1	6.6 E1	8.5
Titanium	1.1 E1	8.8	3.0 E1*	9.3	>1.0 E3	>1.4 E2
Tungsten	<1.1	<3.0 E-1	<1.0	<3.5 E-1	2.0 E1	<2.9[4]
Uranium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	8.0	<1.3[4]
Vanadium	≤5.7 E-1	≤3.0 E-1	1.0	≤3.3 E-1	6.8 E1	8.8
Ytterbium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	≤4.0	<8.2 E-1
Yttrium	<1.1	<3.0 E-1	<1.0	<3.5 E-1	3.0 E1	3.9
Zinc	1.7 E2	3.0 E1	6.8 E1	3.6 E1	>1.0 E3	>1.6 E2
Zirconium	4.0	<3.0 E-1	2.0	<4.8 E-1	5.9 E1	7.6

1
2 = Concentrations in µg/g. SSMS analysis.

	Organic Loading	Percent of Tar and Oil Loading
Probe	17.6 mg/ml	3.90%
ESP	33.1 mg/ml	93.95%
Filter	29.3 mg/ml	2.15%

3 = Less than numbers not included unless 10% of average.
4 = Less than numbers included.
5 = Tar and Oil Fraction 87.13%: Particulate Fraction 12.87% of composite.
NR = Not reported
* = This element heterogeneous in this sample.
~ = Approximately.
LB = Less than or equal to blank.

TABLE F-26. ELEMENTAL CONCENTRATIONS IN PRODUCT GAS VAPORS

	Acid-Base Impingers Collection (µg/Nm3)	Persulfate Impingers Collection (µg/Nm3)	Ratio Acid-Base/Persulfate
Aluminum*	BV¹	5,100	–
Antimony**	BV	<10	–
Arsenic**	130	160	0.81
Barium*	LB²	64	–
Beryllium	<69	<15	<4.6
Bismuth	<69	<15	<4.6
Boron*	530	BV	–
Bromine	LB	370	–
Cadmium	<69	<15	<4.6
Calcium*	510	23,000	0.02
Carbon	NR³	NR	–
Cerium	<69	LB	–
Cesium	<69	51	1.4
Chlorine	>230,000	>34,000	>6.8
Chromium*	14	41	0.34
Cobalt*	23	<21	<1.1
Copper*	23	<3.5	<6.6
Dysprosium	<69	<15	<4.6
Erbium	<69	<15	<4.6
Europium	<69	<15	<4.6
Fluorine	~86	~3,400	~0.02
Gadolinium	<69	<15	<4.6
Gallium	83	LB	–
Germanium	<69	12	<5.8
Gold	<69	<15	<4.6

(Continued)

TABLE F-26. Continued

	Acid-Base Impingers Collection (µg/Nm3)	Persulfate Impingers Collection (µg/Nm3)	Ratio Acid-Base/Persulfate
Hafnium	<69	<15	<4.6
Holmium	<69	<15	<4.6
Hydrogen	NR	<15	–
Indium*	–	–	–
Iodine	160	LB	–
Iridium	<69	<15	<4.6
Iron*	210	710	0.30
Lanthanum	<69	LB	–
Lead	LB	170	–
Lithium	32	51	0.63
Lutetium	<69	<15	<4.6
Magnesium*	89	190	0.47
Manganese*	290	14	21
Mercury**	1.4	11	0.13
Molybdenum	29	11	2.6
Neodymium	<69	<120	<0.58
Nickel*	43	48	0.90
Niobium	<23	7.1	<3.2
Nitrogen	NR	NR	–
Osmium	<69	<15	<4.6
Oxygen	NR	NR	–
Palladium	<69	<15	<4.6
Phosphorous	7200	3600	2
Platinum	<69	<15	<4.6
Potassium*	LB	LB	–
Praseodymium	<69	<39	<1.8

(Continued)

TABLE F-26. Continued

	Acid-Base Impingers Collection (g/Nm3)	Persulfate Impingers Collection (g/Nm3)	Ratio Acid-Base/Persulfate
Rhenium	<69	<15	<4.6
Rhodium	<69	<15	<4.6
Rubidium	<23	18	<1.3
Ruthenium	<69	<15	<4.6
Samarium	<69	<15	<4.6
Scandium	<69	<13	<5.3
Selenium**	5.7	99	0.06
Silicon	LB	>25,000	–
Silver	<69	Contaminated	–
Sodium*	790	2,600	0.30
Strontium	LB	240	–
Sulfur	150,000	>24,000	>6.2
Tantalum	<620	<15	<41
Tellurium	140	BV	–
Terbium	<69	<15	<4.6
Thallium	<69	<15	<4.6
Thorium	<690	110	<6.3
Thulium	<69	<15	<4.6
Tin	<69	<15	<4.6
Titanium*	23	<17	<1.3
Tungsten	<160	<15	<11
Uranium	<170	<84	<2.0
Vanadium*	23	<10	<2.3
Ytterbium	<69	<15	<4.6
Yttrium	<69	3.6	<19
Zinc*	190	55	3.4
Zirconium	49	BV	–

*ICPES

**AAS

[1] BV

[2] LB = Value less than or equal to blank value.

[3] Not reported

[4] Indium used as internal standard for SSMS.

TABLE F-27. RESULTS OF ICPES/AAS AND SSMS ELEMENTAL ANALYSES OF GASIFIER ASH, CYCLONE DUST, AND LIGNITE

	GASIFIER ASH[a]				CYCLONE DUST[a]		LIGNITE[a]			
	12/14 2330 Hours						12/13 0700 Hours		12/13 1415 Hours	
	RN-126		RN-147		RN-153 and RN-154 COMPOSITE		RN-73		RN-77	
	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS
Aluminum	45,000	>1 E3	34,000	>1 E3	23,000	>1 E3	5,600	>1 E3	5,900	>1 E3
Antimony	0.57*	1	1.1*	6	0.6*	2	<0.5*	<1 E-1	<0.5*	<2 E-1
Arsenic	56*	3.8 E1	61*	6.8 E1	63*	1.9 E1	21*	2.5 E1	25*	4
Barium	3,400	>1 E3	3,200	>1 E3	1,700	>1 E3	460	>1 E3	400	9 E2
Beryllium		3 E-1		4		7 E-1		1		3 E-1
Bismuth		<2 E-1		<5 E-1		2 E-1		<1 E-1		<2 E-1
Boron	110	7.6 E1	88	7.6 E2	69	1.9 E2	32	9.5 E1	37	4.5 E-1
Bromine		3		7		3		1		2
Cadmium		<2 E-1		6		<1 E-1		3		3
Calcium	96,000	>1 E3	96,000	>1 E3	35,000	>1 E3	12,000	>1 E3	12,000	>1 E3
Carbon		NR*		NR		NR		NR		NR
Cerium		4.7 E1		4.3 E1		2.4 E1		4		5
Cesium		2		2		3		6 E-1		3 E-1
Chlorine		4.5 E1		4.1 E1		5.1 [illegible]		1.9 E1		1.4 E1
Chromium	<0.2	2.1 E1	<0.2	1.7 E1		3.6 E1		7		2
Cobalt	17	1	14	6	43	2	1.6	≤ 2 E-1	4.9	≤ 3 E-1
Copper	44	2	42	4.4 E1	8.8	1.2 E1	2.3	9	2.6	6
Dysprosium		2		3	29	4	7.0	<1 E-1	8.0	<2 E-1
Erbium		7 E-1		1		8 E-1		<1 E-1		<2 E-1
Europium		1		4		1		≤ 2 E-1		3 E-1
Fluorine		~1.6 E2		~5.1 E2		~1.4 E2		~2.8 E1		~6.7 E1
Gadolinium		2		4		2		<1 E-1		≤ 4 E-1
Gallium		1.5 E1		3.7 E1		1.2 E1		2		2
Germanium		4		7		2		<1 E-1		<2 E-1
Gold		<2 E-1		<5 E-1		<1 E-1		<2 E-1		<2 E-1

(Continued)

TABLE F-27. Continued

	GASIFIER ASH[a]				CYCLONE DUST[a]		LIGNITE[a]			
	12/14 2330 Hours						12/13 0700 Hours		12/13 1415 Hours	
	RM-126		RM-147		RM-153 and RM-154 COMPOSITE		RM-73		RM-77	
	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS
Hafnium		≤ 2		<3 E-1		5 E-1		<1 E-1		<2 E-1
Holmium		1		2		1		<1 E-1		<2 E-1
Hydrogen		NR		NR		NR		NR		NR
Indium		NR		NR		NR		NR		NR
Iodine		4 E-1		1		9 E-1		7 E-1		2 E-1
Iridium		<2 E-1		<3 E-1		<1 E-1		<1 E-1		<2 E-1
Iron	56,000	>1 E3	45,000	>1 E3	14,000	>1 E3	20,000	>1 E3	15,000	>1 E3
Lanthanum		4.7 E1		4.5 E1		2.4 E1		4		2
Lead		8		6		3.7 E1		5		2
Lithium		6		4.6 E1		1 E1		9 E-1		2
Lutetium		<2 E-1		<3 E-1		1 E-1		<1 E-1		<2 E-1
Magnesium	22,000	>1 E3	21,000	>1 E3	9,600	>1 E3	3,000	>1 E3	3,000	>1 E3
Manganese	250	2.3 E2	210	>1 E3	67	3.1 E2	12	1.9 E1	14	7.7 E1
Mercury	4.2 E-4	NR	6.1 E-4	NR	0.02	NR	0.11	NR	0.19	NR
Molybdenum	23	5	20	1.6 E1	14	4	4.6	7	5.7	9
Neodymium		9		1.6 E1		1 E1		7 E-1		5 E-1
Nickel	26	7	20	1.3 E1	20	4	3.8	2	6.4	8 E-1
Niobium		3.7 E1		3.5 E1		1.2 E1		2		2
Nitrogen		NR		NR		NR		NR		NR
Osmium		<2 E-1		<3 E-1		<1 E-1		<1 E-1		<2 E-1
Oxygen		NR		NR		NR		NR		NR
Palladium		<2 E-1		<3 E-1		<1 E-1		<1 E-1		<2 E-1
Phosphorus		>1 E3		>1 E3		>1 E3		2.1 E2		>1 E3
Platinum		<2 E-1		<3 E-1		<1 E-1		<1 E-1		<2 E-1
Potassium	7,000	>1 E3	4,200	>1 E3	4,400	>1 E3	800	>1 E3	1,100	>1 E3
Praseodymium		4		1.7 E1		5		3 E-1		4 E-1

(Continued)

TABLE F-27. Continued

	GASIFIER ASH[a]				CYCLONE DUST[a]		LIGNITE[a]			
	12/14 2330 Hours						12/13 0700 Hours		12/13 1415 Hours	
	RM-126		RM-147		RM-153 and RM-154 COMPOSITE		RM-73		RM-77	
	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS
Rhenium		<2 E-1		<3 E-1		<1 E-1		<1 E-1		<2 E-1
Rhodium		<2 E-1		<3 E-1		<1 E-1		<1 E-1		<2 E-1
Rubidium		1.6 E1		2.8 E1		3.1 E1		1		2
Ruthenium		<2 E-1		<3 E-1		<1 E-1		<1 E-1		<2 E-1
Samarium		5		1.7 E1		4		8 E-1		1
Scandium		1.1 E1		1.9 E1		2		2		5 E-1
Selenium	<1*	5	<1*	9	1.2*	3	<0.5*	≤4 E-1	<0.5*	9 E-1
Silicon		>1 E3		>1 E3		>1 E3		>1 E3		>1 E3
Silver		3		≤3		<1 E-1		6		≤8 E-1
Sodium	24,000	>1 E3	22,000	>1 E3	12,000	>1 E3	3,500	>1 E3	3,500	>1 E3
Strontium		>1 E3		>1 E3		>1 E3		>1 E3		7.6 E2
Tantalum		<2 E-1		<3 E-1		<1 E-1		<1 E-1		<2 E-1
Tellurium		≤3 E-1		1		2 E-1		3 E-1		<2 E-1
Terbium		1		4		2		<1 E-1		<2 E-1
Thallium		<2 E-1		<3 E-1		1		<1 E-1		<2 E-1
Thorium		1.7 E1		3.5 E1		4		3		4
Thulium		2 E-1		4 E-1		1 E-1		<1 E-1		<2 E-1
Tin		2		1		8 E-1		<1 E-1		≤4 E-1
Titanium	2,200	>1 E3	1,800	>1 E3	1,200	>1 E3	330	7.8 E2	270	2.2 E2
Tungsten		2		3		2		<1 E-1		<2 E-1
Uranium		6		2.5 E1		3		2		3
Vanadium	90	6.1 E1	71	1.1 E2	56	3 E1	11	2.8 E1	15	1.4 E1
Ytterbium		1		3		9 E-1		<1 E-1		<2 E-1
Yttrium		6 E1		4.8 E1		7		5		3
Zinc	38	1.2 E1	28	9	71	6 E1	8.3	2	8.6	1
Zirconium		1.6 E2		2.1 E2		5.9 E1		2.4 E1		1.3 E1

[a] Concentrations in µg/g.

*Not reported.

TABLE F-28. RESULTS OF ICPES/AAS AND SSMS ELEMENTAL ANALYSES OF ASH PAN WATER, SERVICE WATER, AND ASH PAN CARRY-OVER WATER

	ASH PAN WATER[a]								SERVICE WATER[a]		ASH PAN CARRY-OVER WATER[a]	
	12/13 1930 Hours RN-18		12/14 0000 Hours RN-23		12/14 0640 Hours RN-49		AVERAGE		12/13 1020 Hours RN-5		12/13 1020 Hours RN-4	
	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS
Aluminum	3,900	7 E2	1,000	1 E2	2,200	>9 E2	2,400	>5.7 E2	91	6 E2*	560	>5000
Antimony	<3*	<1	<3*	<1	<3*	2 E1	<3*	<7.3	<3*	<1 E1	<3*	20
Arsenic	23*	1 E1	11*	3	30*	4 E1	21*	1.8 E1	1*	<1 E1	9*	200
Barium	230	1 E3*	91	3 E1	180	8 E2	170	6.1 E2	39	1 E2	214	4000
Beryllium		<1		<1		<1		<1		<1 E1		3
Bismuth		<1		<1		<1		<1		<1 E1		<10
Boron	3,200	3 E1	1,400	7	3,100	4 E2	2,600	1.5 E2	LD**	<1 E1	480	200
Bromine		1 E1		7		8 E1		3.2 E1		1 E2		90
Cadmium		<1		<1		<1		<1		<1 E1		≤10
Calcium	130,000	>1 E4	45,000	>1 E4	100,000	>1 E4	92,000	>1 E4	5,400	>2 E4	38,000	>10,000
Carbon		NR[a]		NR		NR		NR		NR		
Cerium		8		<1		2		<3.7		3 E1		500
Cesium		4		<1		6		<3.7		<1 E1		50
Chlorine		9 E3		5 E2		5 E3		4.8 E3		3 E2		2000
Chromium	<1	7	<1	<1	<1	<1	<1	<3	<1	≤3 E1	<1	100
Cobalt	<6	<1	<6	<1	<6	≤1	<6	≤1	<6	≤2 E1	<6	80
Copper	10	4 E1	3	1 E1	5	3 E1	6	2.7 E1	33	7 E1	<1	600
Dysprosium		<1		<1		<1		<1		<1 E1		≤30
Erbium		<1		<1		<1		<1		<1 E1		<10
Europium		<1		<1		<1		<1		<1 E1		10
Fluorine		~2 E3		~5 E2		~3 E2		~9.3 E2		~2 E1		1000
Gadolinium		<1		<1		<1		<1		<1 E1		≤20
Gallium		9		~3		7		6.3		1 E1		300
Germanium		≤1		<1		5		<2.3		<1 E1		20
Gold		<1		<1		<1		<1		<1 E1		<10
Hafnium		<1		<1		<1		<1		<1 E1		<10
Holmium		<1		<1		<1		<1		<1 E1		<10
Hydrogen		NR		NR		NR		NR		NR		
Indium		NR		NR		NR		NR		NR		
Iodine		3		2		1 E1		5.0		<1 E1		10
Iridium		<1		<1		<1		<1		<1 E1		<10
Iron	3,400	6 E3	540	2 E2	1,900	1 E3	1,900	2.4 E3	200	3 E3	900	<10,000
Lanthanum		6		<1		4		<3.7		5 E1		400
Lead		<1		2		<1		<1.3		<1 E1		300
Lithium		<1		<1		6		<2.7		<1 E1		100
Lutetium		<1		<1		<1		<1		<1 E1		<10
Magnesium	1,900	>1 E4	990	3 E2	1,300	2 E3	1,400	>4.1 E3	630	6 E2	6,100*	>10,000
Manganese	96	3 E2	27	1 E1	50	5 E1	58	1.2 E2	21	4 E1	10	2,000
Mercury	<0.5		<0.5		<0.5		<0.5		<0.5		<0.5*	
Molybdenum	230	7 E1	110	4 E1	240	1 E2	190	7.0 E1	3	3 E2	22	400

(Continued)

TABLE F-28. Continued

	ASH PAN WATER[a]								SERVICE WATER[a]		ASH PAN CARRY-OVER WATER	
	12/13 1930 Hours RM-18		12/14 0000 Hours RM-23		12/14 0640 Hours RM-49		AVERAGE		12/13 1020 Hours RM-5		12/13 1020 Hours RM-4	
	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS
Neodymium		<1		<1		<1		<1		<1 E1		
Nickel	7	6	<3	<1	4	4	<4.7	<3.7	1	8 E1	1	
Niobium		<1		<1		≤4		<2.0		≤1 E1		
Nitrogen		NR		NR		NR		NR		NR		
Osmium		<1		<1		<1		<1		<1 E1		
Oxygen		NR		NR		NR		NR		NR		
Palladium		<1		<1		<1		<1		<1 E1		
Phosphorus		8 E2		6 E1		4 E2		4.2 E2		2 E2		
Platinum		<1		<1		<1		<1		<1 E1		
Potassium	74,000	>1 E4	30,000	>1 E4	75,000	>1 E4	60,000	>1 E4	1,400	1.9 E4	7,600	
Praseodymium		<1		<1		<1		<1		<1 E1		
Rhenium		<1		<1		<1		<1		<1 E1		<10
Rhodium		<1		<1		<1		<1		<1 E1		<10
Rubidium		2 E2		3 E1		2 E2		1.4 E2		1 E1		300
Ruthenium		<1		<1		<1		<1		<1 E1		<10
Samarium		<1		<1		≤1		<1		<1 E1		100
Scandium		<1		<1		≤1		<1		1 E1		100
Selenium	10*	9	<5*	2	6*	2 E1	<7*	1.0 E1	<5*	<1 E1	<5*	≤60
Silicon		>1 E4		9 E2		1 E3		>4.0 E3		4 E3		>10,000
Silver		3 E1		1 E1		2		1.4 E1		<1 E1		20
Sodium	7.6 E5	>1 E4	3.6 E5	>4 E3	5.9 E5	>5 E3	5.7 E5	>6.3 E3	6,300	1.1 E4	86,000*	>10,000
Strontium		>1 E4		1 E3		6 E3		>5.7 E3		2 E2		1,000
Sulfur		>1 E4		7 E2		>1 E4		>6.9 E3		1 E3		>10,000
Tantalum		<1		<1		<1		<1		<1 E1		<10
Tellurium		<1		<1		2		<1.3		<1 E1		<10
Terbium		<1		<1		<1		<1		<1 E1		<10
Thallium		<1		<1		<1		<1		<1 E1		<10
Thorium		<5		<3		<8		<5.3		<1 E2		20
Thulium		<1		<1		<1		<1		<1 E1		<10
Tin		<1		<1		<1		<1		<1 E1		20
Titanium	43	7 E2	<5	1 E2	9	1 E2	<19	3.0 E2	<5	7 E2	<5	>10,000
Tungsten		1 E1		3		2 E1		1.1 E1		2 E1		≤30
Uranium		<4		<2		<6		<4.0		<9 E1		70
Vanadium	3	5 E1	<3	1	<3	2 E1	<3	2.4 E1	<3	2 E1	<3	300
Ytterbium		<1		<1		<1		<1		<1 E1		<10
Yttrium		2		<1		≤1		<1.3		<1 E1		200
Zinc	12	4 E1	<3	2 E1	1	3 E1	<5	3.0 E1	<3	8 E1		1,000
Zirconium		1 E1		<1		≤1 E1		<7.0		≤2 E1	<3	700

[a] Concentrations in μg/liter.

* Value determined by AAS.

** LB = Value less than or equal to blank value.

NR = Not reported.

TABLE F-29. ELEMENTAL ANALYTICAL RESULTS FOR LEACHATES OF GASIFIER ASH AND CYCLONE DUST

	Gasifier Ash RCRA Leachate		Gasifier Ash Neutral Leachate		Cyclone Dust RCRA Leachate		Cyclone Dust Neutral Leachate	
	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*	SSMS	ICPES/AAS*
Aluminum	LB	<50	>2,000	7,600	LB	10,000	>800	64,000
Antimony	<2		<2		5			
Arsenic	30	33*	20	2*	20	3*	20	4*
Barium	1,000	240/680*	LB	<1/120*	900	560/300*	870	<1/390*
Beryllium	<2		<2		<2		<2	
Bismuth	<2		<2		<2		<2	
Boron	98	4,200	400	2,000	2,000	3,900	2,000	3,300
Bromine	LB		50		330		50	
Cadmium	<2	<0.5*	<2	<0.5*	<2	<0.5*	<2	<0.5*
Calcium	>10,000	1,400,000	>10,000	160,000	>10,000	620,000	>10,000	32,000
Cerium	<2		<2		<2		<2	
Cesium	<2		<2		<2		<2	
Chlorine	LB		LB		3,800		LB	
Chromium	6	16/<1*	LB	24/<1*	20	65/<1*	8	53/<1*
Cobalt	<3	<6	<3	9	<3	36	<3	36
Copper	LB	<1	LB	12	LB	49	LB	45
Dysprosium	<2		<2		<2		<2	
Erbium	<2		<2		<2		<2	
Europium	<2		<2		<2		<2	
Fluorine	LB		LB		~170		~65	
Gadolinium	<2		<2		<2		<2	
Gallium	LB		53		LB		53	
Germanium	<2		<2		<2		<2	
Gold	<2		<2		<2		<2	
Hafnium	<2		<2		<2		<2	
Holmium	<2		<2		<2		<2	
Iodine	<2		4		9		4	
Iridium	<2		<2		<2		<2	
Iron	200	<8	600	<8	>10,000	24	LB	12
Lanthanum	<2		<2		<2		<2	
Lead	<3	<2*	LB	<2*	LB	<2*	LB	<2*
Lithium	2		27		9		3	
Lutetium	<2		<2		<2		<2	
Magnesium	7,700	24,000	400	470	1,700	4,100	LB	460
Manganese	4	3	LB	2	LB	10	LB	7
Mercury		<0.5*		<0.5*		<0.5*		<0.5*
Molybdenum	LB	58	LB	69	LB	110	LB	130

(Continued)

TABLE F-29. Continued

	Gasifier Ash RCRA Leachate SSMS	Gasifier Ash RCRA Leachate ICPES/AAS*	Gasifier Ash Neutral Leachate SSMS	Gasifier Ash Neutral Leachate ICPES/AAS*	Cyclone Dust RCRA Leachate SSMS	Cyclone Dust RCRA Leachate ICPES/AAS*	Cyclone Dust Neutral Leachate SSMS	Cyclone Dust Neutral Leachate ICPES/AAS*
Neodymium	<2		<2		<2		<2	
Nickel	20	20	LB	40	10	66	LB	44
Niobium	<2		<2		<2		<2	
Osmium	<2		<2		<2		<2	
Palladium	<2		<2		<2		<2	
Phosphorus	LB		LB		LB		LB	
Platinum	<2		<2		<2		<2	
Potassium	>10,000	15,000	>10,000	13,000	>10,000	10,000	>10,000	8,400
Praseodymium	<2		<2		<2		<2	
Rhenium	<2		<2		<2		<2	
Rhodium	<7		<2		<2		<2	
Rubidium	20		40		20		7	
Ruthenium	<2		<2		<2		<2	
Samarium	<2		<2		<2		<2	
Scandium	≤3		<2		<2		<2	
Selenium	≤10	6*	29	4*	6	1*	10	2*
Silicon	600	5,900	LB	190	800	240	LB	<20
Silver	<2	<0.5*	8	<0.5*	200	<0.5*	40	<0.5*
Sodium	6,000	140,000	>5,000	130,000	>4,000	230,000	LB	230,000
Strontium	9,000		3,000		>10,000		3,000	
Sulfur	>10,000		>10,000		>10,000		>10,000	
Tantalum	<2		<2		<2		<2	
Tellurium	<2		<2		<2		<2	
Terbium	<2		<2		<2		<2	
Thallium	<2		<2		<2		<2	
Thorium	<20		<20		<20		LB	
Thulium	<2		<2		<2		<2	
Tin	<2		<2		<2		<2	
Titanium	50	7	60	37	450	140	60	130
Tungsten	<2		<2		<2		<2	
Uranium	<20		<10		<10		LB	
Vanadium	40	45	10	34	3	100	6	90
Ytterbium	<2		<2		<2		<2	
Yttrium	≤10		6		6		<2	
Zinc	LB	3	LB	12	LB	19	LB	31
Zirconium	<2		<2		<3		<2	

*Value determined by AAS.

F.1.5.2 SSMS Analyses

The following samples were analyzed by SSMS.

SAMPLE NUMBER	SAMPLE DESCRIPTION
4546	Probe Tar and Oil Fraction
4547	ESP Tar and Oil Fraction
4548	Filter Tar and Oil Fraction
4549	Acid Impinger Solutions, RM-31, RM-32 (Composite)
4550	Base Impinger Solutions, RM-33, RM-34 (Composite)
4552	Persulfate Impinger Solution (1st in series), RM-36
4553	Persulfate Impinger Solution (2nd in series), RM-37
4555	Acid Solution Blank
4556	Base Solution Blank
4558	Persulfate Solution Blank
4559	Ash Pan Water, RM-18
4560	Ash Pan Water, RM-23
4561	Ash Pan Carry-Over Water, RM-4
4562	Ash Pan Water, RM-49
4563	Service Water, RM-5
4564	Gasifier Ash, RM-126
4565	Gasifier Ash, RM-147
4566	Lignite, RM-73
4567	Lignite, RM-77
4568	Cyclone Dust, RM-153, RM-154 (Composite)
4665	RCRA Leachate Blank
4666	Neutral Leachate Blank
4667	RCRA Leachate of TE 4658 (Gasifier Ash, RM-95, RM-98, RM-126, RM-147, RM-149 Composite)
4668	Neutral Leachate of TE 4658 (Gasifier Ash, RM-95, RM-98, RM-126, RM-147, RM-149 Composite)
4669	RCRA Leachate of TE 4568 (Cyclone Dust, RM-153, RM-154 Composite)
4670	Neutral Leachate of TE 4568 (Cyclone Dust, RM-153, RM-154 Composite)

4967	Soxhlet Extraction Solid Residues Composite: RM-51 + RM-56 (Probe + Nozzle: Solids + Rinse) RM-50 + RM-58 (ESP Solids + Rinse)
4968	Soxhlet Extraction Solvent Blank (Blank relative to #'s 4546, 4547, 4548)

TABLE F-30. SSMS ANALYSIS OF PROBE TAR AND OIL FRACTION

COMMERCIAL TESTING & ENGINEERING CO.
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Guy Crawford
Radian Corp.
8500 Shoal Creek Blvd.
P.O. Box 9948
Austin, TX 78766

Date: March 31, 1980

Analyst: S. Sweeney

P. O. No.: 33499

Sample No.: 4546
PROBE TAR AND OIL
FRACTION

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

IAD No.: 97-E057-113-13

CONCENTRATION IN ug/ml

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium		Terbium		Ruthenium		Vanadium	≤0.01
Thorium		Gadolinium		Molybdenum	*0.7	Titanium	0.2
Bismuth		Europium		Niobium		Scandium	≤0.01
Lead	0.2	Samarium		Zirconium	0.07	Calcium	8
Thallium		Neodymium		Yttrium		Potassium	4
Mercury	NR	Praseodymium		Strontium	0.1	Chlorine	0.7
Gold		Cerium		Rubidium	0.01	Sulfur	0.8
Platinum		Lanthanum		Bromine	0.2	Phosphorus	0.5
Iridium		Barium	11	Selenium		Silicon	MC
Osmium		Cesium		Arsenic	1	Aluminum	0.5
Rhenium		Iodine		Germanium		Magnesium	3
Tungsten		Tellurium		Gallium	0.9	Sodium	3
Tantalum		Antimony		Zinc	4	Fluorine	*0.9
Hafnium		Tin		Copper	0.1	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.2	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	≤0.01	Carbon	NR
Thulium		Silver		Iron	1	Boron	2
Erbium		Palladium		Manganese	0.01	Beryllium	
Holmium		Rhodium		Chromium	0.3	Lithium	0.05
Dysprosium						Hydrogen	NR

*Heterogeneous
Note: Sample thermally ashed @ 500°C for one hour prior to analysis.

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.02 ug/ml
MC — Major Component >50 μg/ml
INT — Interference

Approved: M L Jacobs

TABLE F-31. SSMS ANALYSIS OF ESP TAR AND OIL FRACTION

COMMERCIAL TESTING & ENGINEERING CO.
Reply to GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-279-9631

To: Mr. Guy Crawford
Radian Corp.
8500 Shoal Creek Blvd.
P.O. Box 9948
Austin, TX 78766

Date: March 31, 1980

Analyst: S. Sweeney

P. O. No.: 33499

Sample No.: 4547
ESP TAR AND OIL FRACTION

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN µg/ml

IAD No.: 97-E057-113-13

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium		Terbium		Ruthenium		Vanadium	<0.01
Thorium		Gadolinium		Molybdenum	0.1	Titanium	0.3
Bismuth		Europium		Niobium		Scandium	≤0.01
Lead	0.2	Samarium		Zirconium		Calcium	6
Thallium		Neodymium		Yttrium		Potassium	6
Mercury	NR	Praseodymium		Strontium	0.1	Chlorine	0.3
Gold		Cerium		Rubidium	0.01	Sulfur	7
Platinum		Lanthanum		Bromine	0.1	Phosphorus	0.8
Iridium		Barium	1	Selenium	≤0.03	Silicon	MC
Osmium		Cesium	0.02	Arsenic	2	Aluminum	0.5
Rhenium		Iodine	0.02	Germanium	0.06	Magnesium	1
Tungsten		Tellurium		Gallium	0.04	Sodium	MC
Tantalum		Antimony	0.09	Zinc	2	Fluorine	≈1
Hafnium		Tin	≤0.02	Copper	0.4	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.08	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	≤0.1	Carbon	NR
Thulium		Silver	*0.2	Iron	0.9	Boron	0.4
Erbium		Palladium		Manganese	0.02	Beryllium	
Holmium		Rhodium		Chromium	0.03	Lithium	*0.04
Dysprosium						Hydrogen	NR

*Heterogeneous
Note: Sample thermally ashed @ 500°C for one hour prior to analysis.

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.01 µg/ml
MC — Major Component >20 µg/ml
INT — Interference

Approved:

TABLE F-32. SSMS ANALYSIS OF FILTER TAR AND OIL FRACTION

COMMERCIAL TESTING & ENGINEERING CO.
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Guy Crawford
Radian Corp.
8500 Shoal Creek Blvd.
P.O. Box 9948
Austin, TX 78766

Date: March 31, 1980

Analyst: S. Sweeney

P. O. No.: 33499

Sample No.: 4548
FILTER TAR AND OIL FRACTION

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN µg/ml

IAD No.: 97-E057-113-13

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium		Terbium		Ruthenium		Vanadium	0.03
Thorium		Gadolinium		Molybdenum	0.3	Titanium	*0.9
Bismuth		Europium		Niobium		Scandium	≤0.01
Lead	≤0.1	Samarium		Zirconium	0.06	Calcium	7
Thallium		Neodymium		Yttrium		Potassium	7
Mercury		Praseodymium		Strontium	0.07	Chlorine	0.4
Gold	NR	Cerium		Rubidium	0.01	Sulfur	0.5
Platinum		Lanthanum		Bromine	0.07	Phosphorus	0.2
Iridium		Barium	8	Selenium		Silicon	24
Osmium		Cesium		Arsenic	*2	Aluminum	0.7
Rhenium		Iodine		Germanium		Magnesium	2
Tungsten		Tellurium		Gallium	*0.9	Sodium	11
Tantalum	*0.3	Antimony		Zinc	3	Fluorine	*1
Hafnium		Tin		Copper	0.5	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.2	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	≤0.03	Carbon	NR
Thulium		Silver		Iron	2	Boron	3
Erbium		Palladium		Manganese	0.04	Beryllium	
Holmium		Rhodium		Chromium	0.2	Lithium	0.05
Dysprosium						Hydrogen	NR

*Heterogeneous

Note: Sample thermally ashed @ 500°C for one hour prior to analysis.

STD — Internal Standard
NR — Not Reported
All elements not detected <0.03 µg/ml
MC — Major Component >100 µg/ml
INT — Interference

Approved: M Jacobs

TABLE F-33. SSMS ANALYSIS OF COMPOSITE ACID IMPINGER SOLUTIONS

COMMERCIAL TESTING & ENGINEERING CO.
Reply to GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS [illegible] · AREA CODE 312 [illegible]
INSTRUMENTAL ANALYSIS DIVISION, [illegible] WEST [illegible] AVENUE, GOLDEN, COLORADO [illegible], PHONE: [illegible]

To: Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: March 24, 1980

P. O. No.: 33434

Analyst: J. Oldham

Sample No.: Te 4549
ACID IMPINGER SOLUTIONS,
RM-31, RM-32 (COMPOSITE)

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN ug/ml

IAD No.: 97-E031-133-16

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	<0.06	Terbium		Ruthenium		Vanadium	0.003
Thorium	<0.08	Gadolinium		Molybdenum	0.04	Titanium	0.09
Bismuth		Europium		Niobium		Scandium	≤0.001
Lead		Samarium		Zirconium	0.02	Calcium	3
Thallium		Neodymium		Yttrium		Potassium	*0.6
Mercury	NR	Praseodymium		Strontium		Chlorine	0.07
Gold		Cerium		Rubidium		Sulfur	0.7
Platinum		Lanthanum		Bromine		Phosphorus	2
Iridium		Barium	0.1	Selenium		Silicon	*0.8
Osmium		Cesium		Arsenic	0.008	Aluminum	0.2
Rhenium		Iodine		Germanium		Magnesium	0.3
Tungsten	≤0.04	Tellurium		Gallium	0.03	Sodium	*0.1
Tantalum		Antimony		Zinc	0.1	Fluorine	*0.1
Hafnium		Tin		Copper	0.03	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.04	Nitrogen	NR
Ytterbium		Cadmium		Cobalt		Carbon	NR
Thulium		Silver		Iron	1	Boron	0.001
Erbium		Palladium		Manganese	0.005	Beryllium	
Holmium		Rhodium		Chromium	0.005	Lithium	0.003
Dysprosium						Hydrogen	NR

* Heterogeneous

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.008 ug/ml
MC — Major Component > 20 ug/ml
INT — Interference

Approved: M Y Jacobs

TABLE F-34. SSMS ANALYSIS OF COMPOSITE BASE IMPINGER SOLUTIONS

COMMERCIAL TESTING & ENGINEERING CO.
Reply to GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: March 24, 1980

P. O. No.: 33434

Analyst: J. Oldham

Sample No.: Te 4550
BASE IMPINGER SOLUTIONS,
RM-33, RM-34 (COMPOSITE)

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN µg/ml

IAD No.: 97-E031-133-16

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	<0.1	Terbium		Ruthenium		Vanadium	≤0.03
Thorium	<0.2	Gadolinium		Molybdenum		Titanium	0.06
Bismuth		Europium		Niobium	≤0.1	Scandium	≤0.01
Lead		Samarium		Zirconium		Calcium	4
Thallium		Neodymium		Yttrium		Potassium	5
Mercury	NR	Praseodymium		Strontium	0.04	Chlorine	MC
Gold		Cerium		Rubidium	<0.01	Sulfur	63
Platinum		Lanthanum		Bromine	0.1	Phosphorus	1
Iridium		Barium	*0.2	Selenium		Silicon	9
Osmium		Cesium	≤0.007	Arsenic	0.04	Aluminum	0.1
Rhenium		Iodine	0.07	Germanium		Magnesium	0.4
Tungsten		Tellurium	0.06	Gallium	≤0.03	Sodium	MC
Tantalum	≤0.2	Antimony		Zinc	0.3	Fluorine	*0.07
Hafnium		Tin		Copper	*1	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.6	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	<0.01	Carbon	NR
Thulium		Silver		Iron	0.4	Boron	0.04
Erbium		Palladium		Manganese	≤0.01	Beryllium	
Holmium		Rhodium		Chromium	0.02	Lithium	0.01
Dysprosium						Hydrogen	NR

*Heterogeneous
Note: Only 1 ml used due to high salt content.

STD — Internal Standard
NR — Not Reported
All elements not detected <0.02 µg/ml
MC — Major Component >100 µg/ml
INT — Interference

Approved: M S Jacobs

TABLE F-35. SSMS ANALYSIS OF PERSULFATE IMPINGER SOLUTION (1ST IN SERIES)

COMMERCIAL TESTING & ENGINEERING CO.
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: March 24, 1980

Analyst: J. Oldham

P. O. No.: 33434

Sample No.: Te 4552
PERSULFATE IMPINGER SOLUTION
(1st in series), RM-36

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN µg/ml

IAD No.: 97-E031-133-16

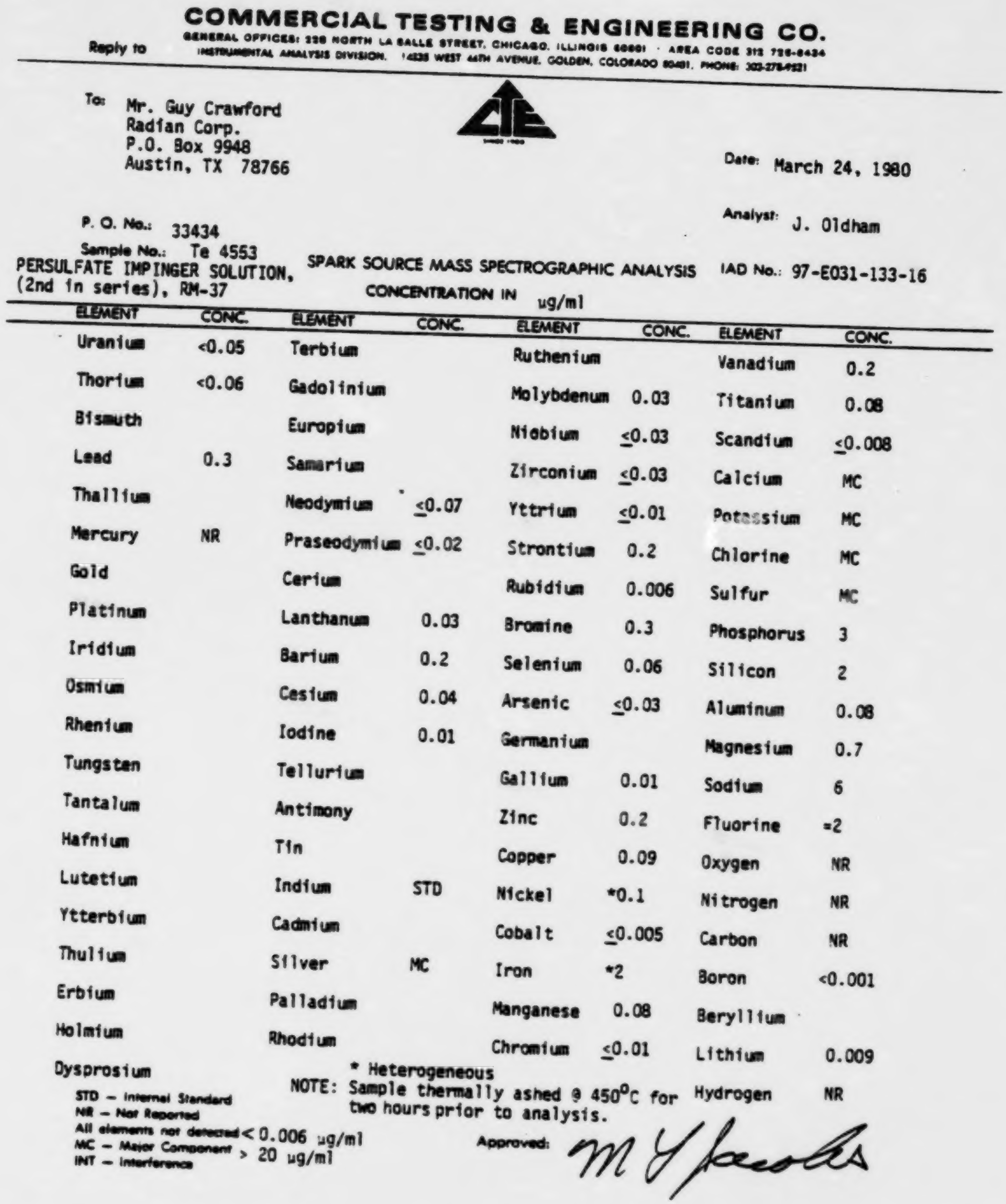
ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	≤0.02	Terbium		Ruthenium		Vanadium	0.01
Thorium	0.06	Gadolinium		Molybdenum	0.02	Titanium	15
Bismuth		Europium		Niobium	0.004	Scandium	≤0.002
Lead	0.02	Samarium		Zirconium	0.02	Calcium	2
Thallium		Neodymium		Yttrium	0.002	Potassium	MC
Mercury	NR	Praseodymium		Strontium	0.05	Chlorine	0.4
Gold		Cerium		Rubidium	0.01	Sulfur	10
Platinum		Lanthanum		Bromine	0.03	Phosphorus	5
Iridium		Barium	0.1	Selenium		Silicon	MC
Osmium		Cesium	0.004	Arsenic	0.006	Aluminum	>3
Rhenium		Iodine	0.003	Germanium	0.007	Magnesium	6
Tungsten		Tellurium	0.01	Gallium	0.01	Sodium	>8
Tantalum		Antimony		Zinc	0.05	Fluorine	=0.005
Hafnium		Tin		Copper	0.02	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.01	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	≤0.002	Carbon	NR
Thulium		Silver	MC	Iron	MC	Boron	0.007
Erbium		Palladium		Manganese	0.4	Beryllium	
Holmium		Rhodium		Chromium	0.3	Lithium	0.02
Dysprosium						Hydrogen	NR

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.003 µg/ml
MC — Major Component >20 µg/ml
INT — Interference

Note: Sample thermally ashed @ 450° C for two hours prior to analysis.

Approved: M L Jacobs

TABLE F-36. SSMS ANALYSIS OF PERSULFATE IMPINGER SOLUTION (2ND IN SERIES)



COMMERCIAL TESTING & ENGINEERING CO.

Reply to
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: March 24, 1980

P. O. No.: 33434

Analyst: J. Oldham

Sample No.: Te 4553
PERSULFATE IMPINGER SOLUTION,
(2nd in series), RM-37

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN ug/ml

IAD No.: 97-E031-133-16

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	<0.05	Terbium		Ruthenium		Vanadium	0.2
Thorium	<0.06	Gadolinium		Molybdenum	0.03	Titanium	0.08
Bismuth		Europium		Niobium	≤0.03	Scandium	≤0.008
Lead	0.3	Samarium		Zirconium	≤0.03	Calcium	MC
Thallium		Neodymium	≤0.07	Yttrium	≤0.01	Potassium	MC
Mercury	NR	Praseodymium	≤0.02	Strontium	0.2	Chlorine	MC
Gold		Cerium		Rubidium	0.006	Sulfur	MC
Platinum		Lanthanum	0.03	Bromine	0.3	Phosphorus	3
Iridium		Barium	0.2	Selenium	0.06	Silicon	2
Osmium		Cesium	0.04	Arsenic	≤0.03	Aluminum	0.08
Rhenium		Iodine	0.01	Germanium		Magnesium	0.7
Tungsten		Tellurium		Gallium	0.01	Sodium	6
Tantalum		Antimony		Zinc	0.2	Fluorine	≈2
Hafnium		Tin		Copper	0.09	Oxygen	NR
Lutetium		Indium	STD	Nickel	*0.1	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	≤0.005	Carbon	NR
Thulium		Silver	MC	Iron	*2	Boron	<0.001
Erbium		Palladium		Manganese	0.08	Beryllium	
Holmium		Rhodium		Chromium	≤0.01	Lithium	0.009
Dysprosium						Hydrogen	NR

* Heterogeneous

NOTE: Sample thermally ashed @ 450°C for two hours prior to analysis.

STD – Internal Standard
NR – Not Reported
All elements not detected < 0.006 μg/ml
MC – Major Component > 20 μg/ml
INT – Interference

Approved: M Y Jacobs

TABLE F-37. SSMS ANALYSIS OF ACID SOLUTION BLANK

COMMERCIAL TESTING & ENGINEERING CO.
Reply to GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: March 24, 1980

Analyst: J. Oldham

P. O. No.: 33434
Sample No.: Te 4555
ACID SOLUTION BLANK

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN µg/ml

IAD No.: 97-E031-133-16

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	<0.007	Terbium		Ruthenium		Vanadium	<0.001
Thorium	<0.008	Gadolinium		Molybdenum	0.03	Titanium	0.01
Bismuth		Europium		Niobium		Scandium	<0.001
Lead	0.004	Samarium		Zirconium	0.003	Calcium	0.5
Thallium		Neodymium		Yttrium		Potassium	0.4
Mercury	NR	Praseodymium		Strontium	0.005	Chlorine	0.05
Gold		Cerium		Rubidium	<0.001	Sulfur	0.1
Platinum		Lanthanum		Bromine	0.03	Phosphorus	0.2
Iridium		Barium	0.01	Selenium		Silicon	1
Osmium		Cesium	0.001	Arsenic	<0.001	Aluminum	>0.9
Rhenium		Iodine	0.02	Germanium		Magnesium	0.1
Tungsten		Tellurium	0.002	Gallium	0.001	Sodium	>2
Tantalum		Antimony		Zinc	0.06	Fluorine	≈0.07
Hafnium		Tin		Copper	0.006	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.004	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	<0.001	Carbon	NR
Thulium		Silver		Iron	0.02	Boron	
Erbium		Palladium		Manganese	0.002	Beryllium	
Holmium		Rhodium		Chromium	0.004	Lithium	<0.001
Dysprosium						Hydrogen	NR

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.001 µg/ml
MC — Major Component >10 µ g/ml
INT — Interference

Approved: M Jacobs

TABLE F-38. SSMS ANALYSIS OF BASE SOLUTION BLANK

COMMERCIAL TESTING & ENGINEERING CO.
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: March 24, 1980

Analyst: J. Oldham

P. O. No.: 33434

Sample No.: Te 4556

BASE SOLUTION BLANK

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN ug/ml

IAD No.: 97-E031-133-16

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	<0.2	Terbium		Ruthenium		Vanadium	<0.01
Thorium	<0.2	Gadolinium		Molybdenum	0.06	Titanium	0.3
Bismuth		Europium		Niobium	≤0.2	Scandium	<0.01
Lead	*0.2	Samarium		Zirconium		Calcium	4
Thallium		Neodymium		Yttrium		Potassium	6
Mercury	NR	Praseodymium		Strontium	0.1	Chlorine	1
Gold		Cerium		Rubidium	0.01	Sulfur	0.3
Platinum		Lanthanum		Bromine	0.1	Phosphorus	0.1
Iridium		Barium	0.2	Selenium		Silicon	49
Osmium		Cesium		Arsenic		Aluminum	0.5
Rhenium		Iodine		Germanium		Magnesium	1
Tungsten		Tellurium	≤0.04	Gallium	≤0.02	Sodium	MC
Tantalum		Antimony		Zinc	≤0.3	Fluorine	≈3
Hafnium		Tin		Copper	0.03	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.03	Nitrogen	NR
Ytterbium		Cadmium		Cobalt		Carbon	NR
Thulium		Silver		Iron	2	Boron	0.05
Erbium		Palladium		Manganese	0.03	Beryllium	
Holmium		Rhodium		Chromium	0.05	Lithium	<0.01
Dysprosium						Hydrogen	NR

*Heterogeneous
Note: Only 1 ml of sample used due to high salt content.

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.02 ug/ml
MC — Major Component >100 ug/ml
INT — Interference

Approved: M Y Jacobs

TABLE F-39. SSMS ANALYSIS OF PERSULFATE SOLUTION BLANK

COMMERCIAL TESTING & ENGINEERING CO.
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: March 24, 1980

Analyst: J. Oldham

P. O. No.: 33434

Sample No.: Te 4558

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

IAD No.: 97-E031-133-16

PERSULFATE SOLUTION BLANK

CONCENTRATION IN µg/ml

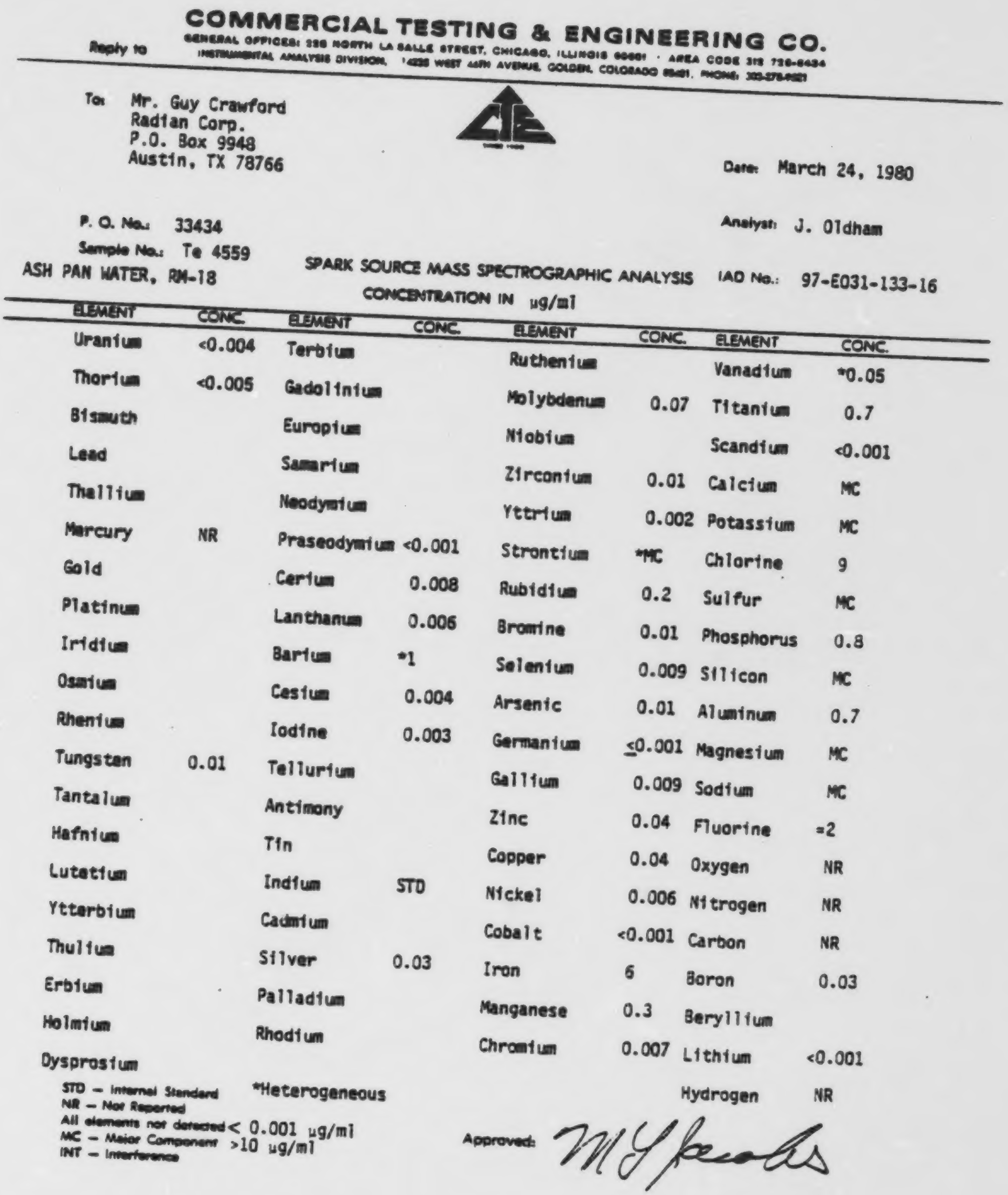
ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	<0.03	Terbium		Ruthenium		Vanadium	0.003
Thorium	<0.03	Gadolinium		Molybdenum	0.1	Titanium	0.5
Bismuth		Europium		Niobium		Scandium	≤0.004
Lead	0.2	Samarium		Zirconium	0.02	Calcium	MC
Thallium		Neodymium		Yttrium	≤0.003	Potassium	16
Mercury	NR	Praseodymium		Strontium	0.06	Chlorine	2
Gold		Cerium	0.009	Rubidium	0.003	Sulfur	8
Platinum		Lanthanum	0.01	Bromine	0.08	Phosphorus	3
Iridium		Barium	0.2	Selenium	≤0.02	Silicon	6
Osmium		Cesium	0.01	Arsenic	0.006	Aluminum	0.8
Rhenium		Iodine	0.02	Germanium	≤0.007	Magnesium	7
Tungsten		Tellurium	0.01	Gallium	0.03	Sodium	3
Tantalum		Antimony	2	Zinc	0.1	Fluorine	≈0.003
Hafnium		Tin		Copper	0.05	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.1	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	0.003	Carbon	NR
Thulium		Silver	MC	Iron	2	Boron	<0.001
Erbium		Palladium		Manganese	0.05	Beryllium	<0.001
Holmium		Rhodium		Chromium	0.004	Lithium	
Dysprosium						Hydrogen	NR

Note: Sample thermally ashed @ 450° C for two hours prior to analysis.

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.003 µg/ml
MC — Major Component >20 µg/ml
INT — Interference

Approved: M Jacobs

TABLE F-40. SSMS ANALYSIS OF ASH PAN WATER (SAMPLE RM-18)



COMMERCIAL TESTING & ENGINEERING CO.
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: March 24, 1980

P. O. No.: 33434
Sample No.: Te 4559
ASH PAN WATER, RM-18

Analyst: J. Oldham

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN µg/ml

IAD No.: 97-E031-133-16

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	<0.004	Terbium		Ruthenium		Vanadium	*0.05
Thorium	<0.005	Gadolinium		Molybdenum	0.07	Titanium	0.7
Bismuth		Europium		Niobium		Scandium	<0.001
Lead		Samarium		Zirconium	0.01	Calcium	MC
Thallium		Neodymium		Yttrium	0.002	Potassium	MC
Mercury	NR	Praseodymium	<0.001	Strontium	*MC	Chlorine	9
Gold		Cerium	0.008	Rubidium	0.2	Sulfur	MC
Platinum		Lanthanum	0.006	Bromine	0.01	Phosphorus	0.8
Iridium		Barium	*1	Selenium	0.009	Silicon	MC
Osmium		Cesium	0.004	Arsenic	0.01	Aluminum	0.7
Rhenium		Iodine	0.003	Germanium	≤0.001	Magnesium	MC
Tungsten	0.01	Tellurium		Gallium	0.009	Sodium	MC
Tantalum		Antimony		Zinc	0.04	Fluorine	≈2
Hafnium		Tin		Copper	0.04	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.006	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	<0.001	Carbon	NR
Thulium		Silver	0.03	Iron	6	Boron	0.03
Erbium		Palladium		Manganese	0.3	Beryllium	
Holmium		Rhodium		Chromium	0.007	Lithium	<0.001
Dysprosium						Hydrogen	NR

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.001 µg/ml
MC — Major Component >10 µg/ml
INT — Interference

*Heterogeneous

Approved: M J Jacobs

TABLE F-41. SSMS ANALYSIS OF ASH PAN WATER (SAMPLE RM-23)

COMMERCIAL TESTING & ENGINEERING CO.
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: March 24, 1980

Analyst: J. Oldham

P. O. No.: 33434
Sample No.: Te 4560
ASH PAN WATER, RM-23

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN μg/ml

IAD No.: 97-E031-133-16

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	<0.002	Terbium		Ruthenium		Vanadium	0.001
Thorium	<0.003	Gadolinium		Molybdenum	0.04	Titanium	0.1
Bismuth		Europium		Niobium	<0.001	Scandium	<0.001
Lead	0.002	Samarium		Zirconium		Calcium	MC
Thallium		Neodymium		Yttrium	<0.001	Potassium	MC
Mercury	NR	Praseodymium		Strontium	1	Chlorine	0.5
Gold		Cerium		Rubidium	0.03	Sulfur	0.7
Platinum		Lanthanum		Bromine	0.007	Phosphorus	0.06
Iridium		Barium	0.03	Selenium	0.002	Silicon	*0.9
Osmium		Cesium	<0.001	Arsenic	0.003	Aluminum	0.1
Rhenium		Iodine	0.002	Germanium	<0.001	Magnesium	0.3
Tungsten	0.003	Tellurium	<0.001	Gallium	0.003	Sodium	>4
Tantalum		Antimony		Zinc	0.02	Fluorine	≈0.5
Hafnium		Tin		Copper	0.01	Oxygen	NR
Lutetium		Indium	STD	Nickel	<0.001	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	<0.001	Carbon	NR
Thulium		Silver	0.01	Iron	0.2	Boron	0.007
Erbium		Palladium		Manganese	0.01	Beryllium	
Holmium		Rhodium		Chromium	<0.001	Lithium	<0.001
Dysprosium						Hydrogen	NR

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.001 μg/ml
MC — Major Component >10 μg/ml
INT — Interference

*Heterogeneous

Approved: M Jacobs

TABLE F-42.- SSMS ANALYSIS OF ASH PAN CARRY-OVER WATER (SAMPLE RM-4)

COMMERCIAL TESTING & ENGINEERING CO.
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Guy Crawford
Radian Corp.
8500 Shoal Creek Blvd.
P.O. Box 9948
Austin, TX 78766

Date: April 2, 1980

Analyst: S. Sweeney

P. O. No.: 33499

Sample No.: 4561
ASH PAN CARRYOVER
WATER, RM-4

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN µg/ml

IAD No.: 97-E057-113-13

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	0.07	Terbium	≤0.01	Ruthenium		Vanadium	0.3
Thorium	0.2	Gadolinium	≤0.02	Molybdenum	0.4	Titanium	MC
Bismuth		Europium	0.01	Niobium	0.2	Scandium	0.1
Lead	0.3	Samarium	0.1	Zirconium	0.7	Calcium	MC
Thallium		Neodymium	0.1	Yttrium	0.2	Potassium	MC
Mercury	NR	Praseodymium	0.05	Strontium	1	Chlorine	2
Gold		Cerium	0.5	Rubidium	0.3	Sulfur	MC
Platinum		Lanthanum	0.4	Bromine	0.09	Phosphorus	6
Iridium		Barium	4	Selenium	≤0.06	Silicon	MC
Osmium		Cesium	0.05	Arsenic	0.2	Aluminum	>5
Rhenium		Iodine	0.01	Germanium	0.02	Magnesium	MC
Tungsten	≤0.03	Tellurium		Gallium	0.3	Sodium	MC
Tantalum		Antimony	0.02	Zinc	1	Fluorine	=1
Hafnium		Tin	0.02	Copper	0.6	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.2	Nitrogen	NR
Ytterbium		Cadmium	≤0.01	Cobalt	0.08	Carbon	NR
Thulium		Silver	0.02	Iron	MC	Boron	0.2
Erbium	≤0.01	Palladium		Manganese	2	Beryllium	0.003
Holmium	≤0.01	Rhodium		Chromium	0.1	Lithium	0.1
Dysprosium	≤0.03					Hydrogen	NR

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.01 µg/ml
MC — Major Component >10 µg/ml
INT — Interference

Approved: M J Jacobs

TABLE F-43. SSMS ANALYSIS OF ASH PAN WATER (SAMPLE RM-49)

COMMERCIAL TESTING & ENGINEERING CO.

Reply to GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: March 24, 1980

P. O. No.: 33434

Analyst: J. Oldham

Sample No.: Te 4562
ASH PAN WATER, RM-49

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN µg/ml

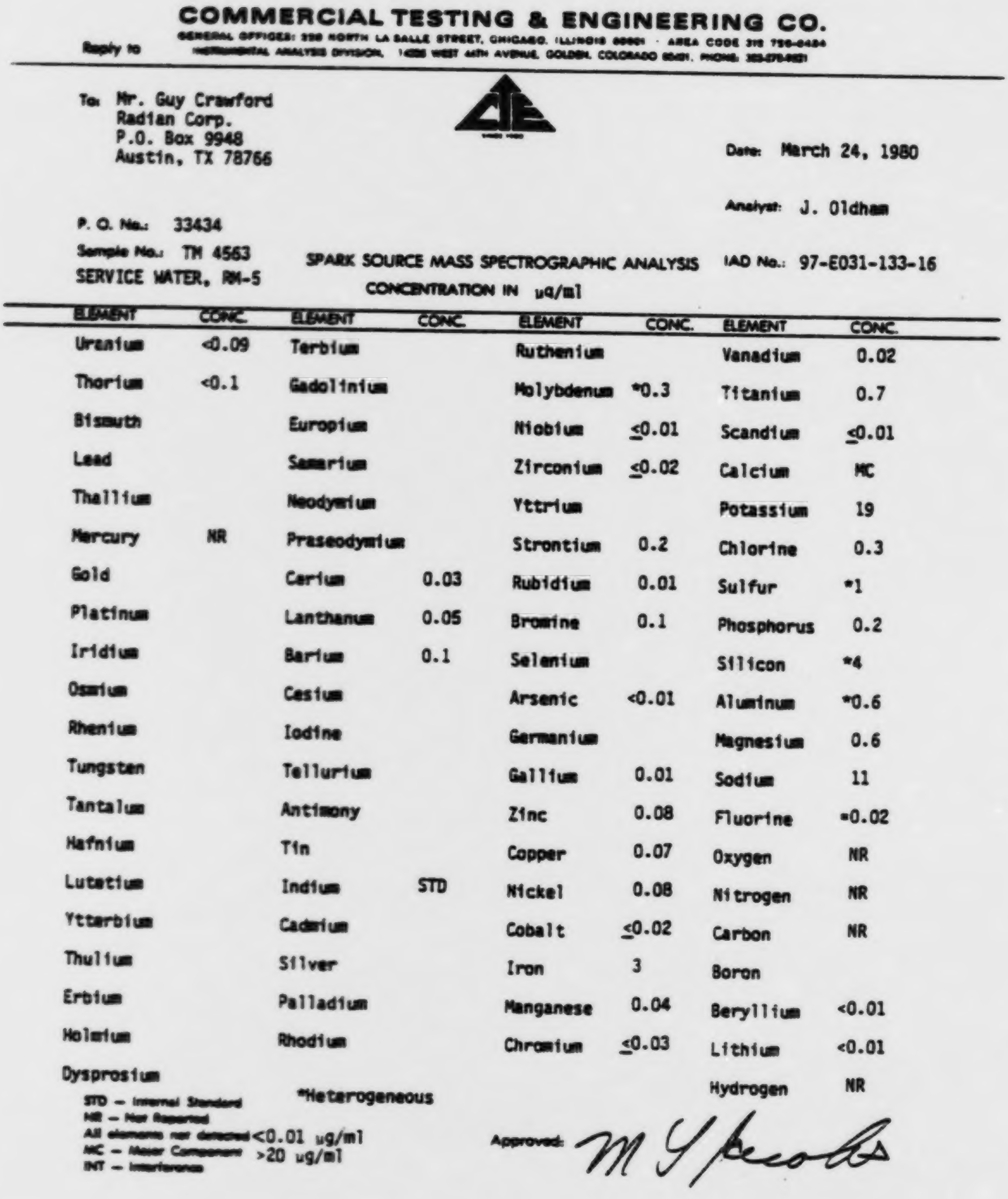
IAD No.: 97-E031-133-16

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	<0.006	Terbium		Ruthenium		Vanadium	0.02
Thorium	<0.008	Gadolinium		Molybdenum	0.1	Titanium	0.1
Bismuth		Europium		Niobium	≤0.004	Scandium	≤0.001
Lead		Samarium		Zirconium	≤0.01	Calcium	MC
Thallium		Neodymium		Yttrium	≤0.001	Potassium	MC
Mercury	NR	Praseodymium		Strontium	6	Chlorine	5
Gold		Cerium	0.002	Rubidium	0.2	Sulfur	MC
Platinum		Lanthanum	0.004	Bromine	0.08	Phosphorus	0.4
Iridium		Barium	0.8	Selenium	0.02	Silicon	1
Osmium		Cesium	0.006	Arsenic	0.04	Aluminum	>0.9
Rhenium		Iodine	0.01	Germanium	0.005	Magnesium	2
Tungsten	0.02	Tellurium	0.002	Gallium	0.007	Sodium	>5
Tantalum		Antimony	0.02	Zinc	0.03	Fluorine	≈0.3
Hafnium		Tin		Copper	0.03	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.004	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	≤0.001	Carbon	NR
Thulium		Silver	0.002	Iron	1	Boron	0.4
Erbium		Palladium		Manganese	0.05	Beryllium	
Holmium		Rhodium		Chromium	<0.001	Lithium	0.006
Dysprosium						Hydrogen	NR

STD — Internal Standard
NR — Not Reported
All elements not detected <0.001 µg/ml
MC — Major Component >MC µg/ml
INT — Interference

Approved: M J Jacobs

TABLE F-44. SSMS ANALYSIS OF SERVICE WATER (SAMPLE RM-5)



COMMERCIAL TESTING & ENGINEERING CO.
Reply to
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: March 24, 1980

Analyst: J. Oldham

P. O. No.: 33434
Sample No.: TM 4563
SERVICE WATER, RM-5

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN μg/ml

IAD No.: 97-E031-133-16

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	<0.09	Terbium		Ruthenium		Vanadium	0.02
Thorium	<0.1	Gadolinium		Molybdenum	*0.3	Titanium	0.7
Bismuth		Europium		Niobium	≤0.01	Scandium	≤0.01
Lead		Samarium		Zirconium	≤0.02	Calcium	MC
Thallium		Neodymium		Yttrium		Potassium	19
Mercury	NR	Praseodymium		Strontium	0.2	Chlorine	0.3
Gold		Cerium	0.03	Rubidium	0.01	Sulfur	*1
Platinum		Lanthanum	0.05	Bromine	0.1	Phosphorus	0.2
Iridium		Barium	0.1	Selenium		Silicon	*4
Osmium		Cesium		Arsenic	<0.01	Aluminum	*0.6
Rhenium		Iodine		Germanium		Magnesium	0.6
Tungsten		Tellurium		Gallium	0.01	Sodium	11
Tantalum		Antimony		Zinc	0.08	Fluorine	*0.02
Hafnium		Tin		Copper	0.07	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.08	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	≤0.02	Carbon	NR
Thulium		Silver		Iron	3	Boron	
Erbium		Palladium		Manganese	0.04	Beryllium	<0.01
Holmium		Rhodium		Chromium	≤0.03	Lithium	<0.01
Dysprosium						Hydrogen	NR

STD — Internal Standard
NR — Not Reported
All elements not detected <0.01 μg/ml
MC — Major Component >20 μg/ml
INT — Interference

*Heterogeneous

Approved: M S Jacobs

TABLE F-45. SSMS ANALYSIS OF GASIFIER ASH (SAMPLE RM-126)

COMMERCIAL TESTING & ENGINEERING CO.
GENERAL OFFICES: [illegible] NORTH LA SALLE STREET, CHICAGO, ILLINOIS [illegible] · AREA CODE [illegible]
Reply to INSTRUMENTAL ANALYSIS DIVISION, [illegible] WEST [illegible] AVENUE, GOLDEN, COLORADO [illegible], PHONE [illegible]

To:
Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: March 24, 1980

Analyst: J. Oldham

P. O. No.: 33434
Sample No.: TM 4564
GASIFIER ASH, RM-126

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN PPM WEIGHT

IAD No.: 97-E031-133-16

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	6	Terbium	1	Ruthenium		Vanadium	61
Thorium	17	Gadolinium	2	Molybdenum	5	Titanium	MC
Bismuth		Europium	1	Niobium	37	Scandium	11
Lead	8	Samarium	5	Zirconium	160	Calcium	MC
Thallium		Neodymium	9	Yttrium	60	Potassium	MC
Mercury	NR	Praseodymium	4	Strontium	MC	Chlorine	45
Gold		Cerium	47	Rubidium	16	Sulfur	MC
Platinum		Lanthanum	47	Bromine	3	Phosphorus	MC
Iridium		Barium	MC	Selenium	5	Silicon	MC
Osmium		Cesium	2	Arsenic	38	Aluminum	MC
Rhenium		Iodine	0.4	Germanium	4	Magnesium	MC
Tungsten	2	Tellurium	≤0.3	Gallium	15	Sodium	MC
Tantalum		Antimony	1	Zinc	12	Fluorine	≈160
Hafnium	≤2	Tin	2	Copper	2	Oxygen	NR
Lutetium		Indium	STD	Nickel	7	Nitrogen	NR
Ytterbium	1	Cadmium		Cobalt	1	Carbon	NR
Thulium	0.2	Silver	3	Iron	MC	Boron	76
Erbium	0.7	Palladium		Manganese	230	Beryllium	0.3
Holmium	1	Rhodium		Chromium	21	Lithium	6
Dysprosium	2					Hydrogen	NR

STD — Internal Standard
NR — Not Reported
All elements not detected <0.2 ppm
MC — Major Component > 1,000 ppm
INT — Interference

Approved: M Jacobs

TABLE F-46. SSMS ANALYSIS OF GASIFIER ASH (SAMPLE RM-147)

COMMERCIAL TESTING & ENGINEERING CO.
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: March 24, 1980

Analyst: J. Oldham

P. O. No.: 33434
Sample No.: TM 4565
GASIFIER ASH, RM-147

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN PPM WEIGHT

IAD No.: 97-E031-133-16

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	25	Terbium	4	Ruthenium		Vanadium	110
Thorium	35	Gadolinium	4	Molybdenum	16	Titanium	MC
Bismuth		Europium	4	Niobium	35	Scandium	19
Lead	6	Samarium	17	Zirconium	210	Calcium	MC
Thallium		Neodymium	16	Yttrium	48	Potassium	MC
Mercury	NR	Praseodymium	17	Strontium	MC	Chlorine	41
Gold		Cerium	42	Rubidium	28	Sulfur	MC
Platinum		Lanthanum	45	Bromine	7	Phosphorus	MC
Iridium		Barium	MC	Selenium	9	Silicon	MC
Osmium		Cesium	2	Arsenic	68	Aluminum	MC
Rhenium		Iodine	1	Germanium	7	Magnesium	MC
Tungsten	3	Tellurium	1	Gallium	27	Sodium	MC
Tantalum		Antimony	6	Zinc	9	Fluorine	≈510
Hafnium	3	Tin	1	Copper	44	Oxygen	NR
Lutetium	0.4	Indium	STD	Nickel	13	Nitrogen	NR
Ytterbium	3	Cadmium	6	Cobalt	6	Carbon	NR
Thulium	0.4	Silver	≤3	Iron	MC	Boron	760
Erbium	1	Palladium		Manganese	MC	Beryllium	4
Holmium	2	Rhodium		Chromium	17	Lithium	46
Dysprosium	3					Hydrogen	NR

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.3 ppm
MC — Major Component > 1,000 ppm
INT — Interference

Approved: M Y Jacobs

TABLE F-47. SSMS ANALYSIS OF LIGNITE (SAMPLE RM-73)

COMMERCIAL TESTING & ENGINEERING CO.
GENERAL OFFICES: [illegible] NORTH LA SALLE STREET, CHICAGO, ILLINOIS [illegible] · AREA CODE [illegible]
Reply to INSTRUMENTAL ANALYSIS DIVISION, [illegible] WEST [illegible] AVENUE, GOLDEN, COLORADO [illegible], PHONE [illegible]

To: Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: March 24, 1980

Analyst: J. Oldham

P. O. No.: 33434
Sample No.: TM 4566
LIGNITE, RM-73

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN PPM WEIGHT

IAD No.: 97-E031-133-16

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	2	Terbium		Ruthenium		Vanadium	28
Thorium	3	Gadolinium		Molybdenum	7	Titanium	780
Bismuth		Europium	≤0.2	Niobium	2	Scandium	2
Lead	3	Samarium	0.8	Zirconium	24	Calcium	MC
Thallium		Neodymium	0.7	Yttrium	5	Potassium	MC
Mercury	NR	Praseodymium	0.3	Strontium	MC	Chlorine	19
Gold		Cerium	4	Rubidium	1	Sulfur	MC
Platinum		Lanthanum	4	Bromine	1	Phosphorus	210
Iridium		Barium	MC	Selenium	≤0.4	Silicon	MC
Osmium		Cesium	0.6	Arsenic	25	Aluminum	MC
Rhenium		Iodine	0.7	Germanium		Magnesium	MC
Tungsten		Tellurium	0.3	Gallium	2	Sodium	MC
Tantalum		Antimony		Zinc	2	Fluorine	*23
Hafnium		Tin		Copper	9	Oxygen	NR
Lutetium		Indium	STD	Nickel	2	Nitrogen	NR
Ytterbium		Cadmium	3	Cobalt	≤0.2	Carbon	NR
Thulium		Silver	*6	Iron	MC	Boron	35
Erbium		Palladium		Manganese	19	Beryllium	1
Holmium		Rhodium		Chromium	7	Lithium	0.9
Dysprosium						Hydrogen	NR

* Heterogeneous

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.1 ppm
MC — Major Component > 1,000 ppm
INT — Interference

Approved: M L Jacobs

TABLE F-48. SSMS ANALYSIS OF LIGNITE (SAMPLE RM-77)

COMMERCIAL TESTING & ENGINEERING CO.
Reply to
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: March 24, 1980

Analyst: J. Oldham

P. O. No.: 33434
Sample No.: TM 4567
LIGNITE, RM-77

IAD No.: 97-E031-133-16

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	3	Terbium		Ruthenium		Vanadium	14
Thorium	4	Gadolinium	≤0.4	Molybdenum	9	Titanium	220
Bismuth		Europium	0.3	Niobium	2	Scandium	0.5
Lead	2	Samarium	1	Zirconium	12	Calcium	MC
Thallium		Neodymium	0.5	Yttrium	3	Potassium	MC
Mercury	NR	Praseodymium	0.4	Strontium	760	Chlorine	14
Gold		Cerium	5	Rubidium	2	Sulfur	MC
Platinum		Lanthanum	2	Bromine	2	Phosphorus	MC
Iridium		Barium	900	Selenium	0.9	Silicon	MC
Osmium		Cesium	0.3	Arsenic	4	Aluminum	MC
Rhenium		Iodine	0.2	Germanium		Magnesium	MC
Tungsten		Tellurium		Gallium	2	Sodium	MC
Tantalum		Antimony		Zinc	1	Fluorine	≈67
Hafnium		Tin	≤0.4	Copper	6	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.8	Nitrogen	NR
Ytterbium		Cadmium	3	Cobalt	≤0.3	Carbon	NR
Thulium		Silver	≤0.8	Iron	MC	Boron	45
Erbium		Palladium		Manganese	77	Beryllium	0.3
Holmium		Rhodium		Chromium	2	Lithium	2
Dysprosium						Hydrogen	NR

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.2 ppm
MC — Major Component > 1,000 ppm
INT — Interference

Approved: M Y Jacobs

TABLE F-49. SSMS ANALYSIS OF CYCLONE DUST COMPOSITE (SAMPLES RM-153 AND RM-154)

COMMERCIAL TESTING & ENGINEERING CO.
Reply to
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE 303-278-9521

To: Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: March 24, 1980

P. O. No.: 33434

Analyst: J. Oldham

Sample No.: TM 4568
CYCLONE DUST, RM-153,
RM-154 (COMPOSITE)

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN ppm weight

IAD No.: 97-E031-133-16

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	3	Terbium	2	Ruthenium		Vanadium	30
Thorium	4	Gadolinium	2	Molybdenum	4	Titanium	MC
Bismuth	0.2	Europium	1	Niobium	12	Scandium	2
Lead	37	Samarium	4	Zirconium	59	Calcium	MC
Thallium	1	Neodymium	10	Yttrium	7	Potassium	MC
Mercury	NR	Praseodymium	5	Strontium	MC	Chlorine	51
Gold		Cerium	24	Rubidium	31	Sulfur	MC
Platinum		Lanthanum	24	Bromine	3	Phosphorus	MC
Iridium		Barium	MC	Selenium	3	Silicon	MC
Osmium		Cesium	3	Arsenic	19	Aluminum	MC
Rhenium		Iodine	0.9	Germanium	2	Magnesium	MC
Tungsten	2	Tellurium	0.2	Gallium	12	Sodium	MC
Tantalum		Antimony	2	Zinc	60	Fluorine	≈140
Hafnium	0.5	Tin	0.8	Copper	12	Oxygen	NR
Lutetium	0.1	Indium	STD	Nickel	4	Nitrogen	NR
Ytterbium	0.9	Cadmium		Cobalt	2	Carbon	NR
Thulium	0.1	Silver		Iron	MC	Boron	190
Erbium	0.8	Palladium		Manganese	310	Beryllium	0.7
Holmium	1	Rhodium		Chromium	26	Lithium	10
Dysprosium	4					Hydrogen	NR

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.1 ppm weight
MC — Major Component >1000 ppm weight
INT — Interference

Approved: M S Jacobs

TABLE F-50. SSMS ANALYSIS OF RCRA LEACHATE BLANK

COMMERCIAL TESTING & ENGINEERING CO.
Reply to GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44th AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To:
Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: April 2, 1980

P. O. No.: 33499
Sample No.: 4665
RCRA LEACHATE BLANK

Analyst: S. Sweeney

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN ug/ml

IAD No.: 97-E057-113-13

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium		Terbium		Ruthenium		Vanadium	0.003
Thorium		Gadolinium		Molybdenum	0.1	Titanium	0.05
Bismuth		Europium		Niobium		Scandium	≤0.001
Lead	0.04	Samarium		Zirconium		Calcium	1
Thallium		Neodymium		Yttrium		Potassium	0.8
Mercury	NR	Praseodymium		Strontium	0.004	Chlorine	0.2
Gold		Cerium		Rubidium		Sulfur	0.3
Platinum		Lanthanum		Bromine	0.07	Phosphorus	0.4
Iridium		Barium		Selenium		Silicon	0.2
Osmium		Cesium		Arsenic	0.02	Aluminum	0.1
Rhenium		Iodine		Germanium		Magnesium	0.3
Tungsten		Tellurium		Gallium	0.01	Sodium	1
Tantalum		Antimony		Zinc	0.2	Fluorine	≈0.03
Hafnium		Tin		Copper	0.03	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.02	Nitrogen	NR
Ytterbium		Cadmium		Cobalt		Carbon	NR
Thulium		Silver		Iron	0.2	Boron	0.002
Erbium		Palladium		Manganese	0.004	Beryllium	
Holmium		Rhodium		Chromium	≤0.02	Lithium	0.001
Dysprosium						Hydrogen	NR

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.01 ug/ml
MC — Major Component >10 ug/ml
INT — Interference

Approved: M Jacobs

TABLE F-51. SSMS ANALYSIS OF NEUTRAL LEACHATE BLANK

COMMERCIAL TESTING & ENGINEERING CO.
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To:
Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: April 2, 1980

Analyst: J. Oldham

P. O. No.: 33499
Sample No.: 4666
NEUTRAL LEACHATE BLANK

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN ug/ml

IAD No.: 97-E057-113-13

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	<0.05	Terbium		Ruthenium		Vanadium	≤0.002
Thorium	<0.06	Gadolinium		Molybdenum	0.3	Titanium	0.04
Bismuth		Europium		Niobium		Scandium	≤0.002
Lead	0.03	Samarium		Zirconium		Calcium	1
Thallium		Neodymium		Yttrium		Potassium	5
Mercury	NR	Praseodymium		Strontium	0.007	Chlorine	3
Gold		Cerium		Rubidium	≤0.002	Sulfur	0.2
Platinum		Lanthanum		Bromine	0.02	Phosphorus	0.5
Iridium		Barium	0.03	Selenium		Silicon	*7
Osmium		Cesium		Arsenic	≤0.02	Aluminum	0.2
Rhenium		Iodine		Germanium		Magnesium	0.3
Tungsten		Tellurium		Gallium	0.007	Sodium	*6
Tantalum		Antimony		Zinc	0.05	Fluorine	=0.005
Hafnium		Tin		Copper	0.1	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.1	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	≤0.003	Carbon	NR
Thulium		Silver		Iron	0.4	Boron	
Erbium		Palladium		Manganese	0.01	Beryllium	
Holmium		Rhodium		Chromium	0.002	Lithium	0.003
Dysprosium						Hydrogen	NR

* Heterogeneous

STD — Internal Standard
NR — Not Reported
All elements not detected <0.006 µg/ml
MC — Major Component > 10 µg/ml
INT — Interference

Approved: M Jacobs

TABLE F-52. SSMS ANALYSIS OF RCRA LEACHATE OF GASIFIER ASH COMPOSITE OF RM-95, RM-98, RM-126, RM-147, AND RM-149

COMMERCIAL TESTING & ENGINEERING CO.
GENERAL OFFICES: [illegible] NORTH LA SALLE STREET, CHICAGO, ILLINOIS [illegible] · AREA CODE [illegible]
Reply to INSTRUMENTAL ANALYSIS DIVISION, [illegible] WEST [illegible] AVENUE, GOLDEN, COLORADO [illegible], PHONE: [illegible]

To:
Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: April 2, 1980

Analyst: J. Oldham

P. O. No.: 33499

Sample No.: 4667
RCRA LEACHATE OF TE 4658

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN µg/ml

IAD No.: 97-E057-113-13

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	<0.02	Terbium		Ruthenium		Vanadium	0.04
Thorium	<0.02	Gadolinium		Molybdenum	0.06	Titanium	0.1
Bismuth		Europium		Niobium		Scandium	≤0.003
Lead		Samarium		Zirconium		Calcium	MC
Thallium		Neodymium		Yttrium	≤0.01	Potassium	MC
Mercury	NR	Praseodymium		Strontium	9	Chlorine	0.1
Gold		Cerium		Rubidium	0.02	Sulfur	MC
Platinum		Lanthanum		Bromine	0.02	Phosphorus	0.4
Iridium		Barium	1	Selenium	≤0.01	Silicon	0.8
Osmium		Cesium		Arsenic	0.05	Aluminum	0.02
Rhenium		Iodine		Germanium		Magnesium	8
Tungsten		Tellurium		Gallium	0.002	Sodium	*>6
Tantalum		Antimony		Zinc	*0.01	Fluorine	*0.008
Hafnium		Tin		Copper	0.01	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.04	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	≤0.003	Carbon	NR
Thulium		Silver		Iron	*0.4	Boron	0.1
Erbium		Palladium		Manganese	*0.008	Beryllium	
Holmium		Rhodium		Chromium	0.006	Lithium	0.003
Dysprosium						Hydrogen	NR

* Heterogeneous

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.002 µg/ml
MC — Major Component > 10 µg/ml
INT — Interference

Approved: M [illegible]

TABLE F-53. SSMS ANALYSIS OF NEUTRAL LEACHATE OF GASIFIER ASH COMPOSITE OF RM-95, RM-98, RM-126, RM-147, AND RM-149

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE 303-278-9521

To:

Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: April 2, 1980

Analyst: J. Oldham

P. O. No.: 33499

Sample No.: 4668

NEUTRAL LEACHATE OF TE 4658

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

IAD No.: 97-E057-113-13

CONCENTRATION IN ug/ml

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	<0.01	Terbium		Ruthenium		Vanadium	0.01
Thorium	<0.02	Gadolinium		Molybdenum	0.05	Titanium	0.1
Bismuth		Europium		Niobium		Scandium	≤0.002
Lead	≤0.008	Samarium		Zirconium		Calcium	MC
Thallium		Neodymium		Yttrium	0.006	Potassium	MC
Mercury	NR	Praseodymium		Strontium	3	Chlorine	0.9
Gold		Cerium		Rubidium	0.04	Sulfur	MC
Platinum		Lanthanum		Bromine	0.07	Phosphorus	*0.01
Iridium		Barium	0.2	Selenium	0.02	Silicon	0.2
Osmium		Cesium		Arsenic	0.02	Aluminum	>2
Rhenium		Iodine	0.004	Germanium		Magnesium	0.7
Tungsten		Tellurium		Gallium	0.06	Sodium	>5
Tantalum		Antimony		Zinc	0.01	Fluorine	=0.003
Hafnium		Tin		Copper	0.01	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.06	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	≤0.003	Carbon	NR
Thulium		Silver	0.008	Iron	1	Boron	0.4
Erbium		Palladium		Manganese	0.002	Beryllium	
Holmium		Rhodium		Chromium	0.002	Lithium	0.03
Dysprosium						Hydrogen	NR

* Heterogeneous

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.002 ug/ml
MC — Major Component > 10 ug/ml
INT — Interference

Approved: M L Jacobs

TABLE F-54. SSMS ANALYSIS OF RCRA LEACHATE OF CYCLONE DUST COMPOSITE OF RM-153 AND RM-154

COMMERCIAL TESTING & ENGINEERING CO.
Reply to
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To:
Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: April 2, 1980

P. O. No.: 33499
Sample No.: 4669
RCRA LEACHATE OF TE 4568

Analyst: J. Oldham

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN µg/ml

IAD No.: 97-E057-113-13

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	<0.01	Terbium		Ruthenium		Vanadium	0.006
Thorium	<0.02	Gadolinium		Molybdenum	0.09	Titanium	0.5
Bismuth		Europium		Niobium	≤0.002	Scandium	≤0.002
Lead	0.009	Samarium		Zirconium	≤0.003	Calcium	MC
Thallium		Neodymium		Yttrium	0.006	Potassium	MC
Mercury	NR	Praseodymium		Strontium	MC	Chlorine	4
Gold		Cerium		Rubidium	0.02	Sulfur	MC
Platinum		Lanthanum		Bromine	0.4	Phosphorus	0.03
Iridium		Barium	0.9	Selenium	0.006	Silicon	*1
Osmium		Cesium		Arsenic	0.04	Aluminum	0.009
Rhenium		Iodine	0.009	Germanium		Magnesium	2
Tungsten		Tellurium		Gallium	≤0.003	Sodium	>5
Tantalum		Antimony	*0.005	Zinc	0.01	Fluorine	≈0.2
Hafnium		Tin		Copper	0.03	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.03	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	≤0.003	Carbon	NR
Thulium		Silver	0.2	Iron	*MC	Boron	2
Erbium		Palladium		Manganese	<0.001	Beryllium	
Holmium		Rhodium		Chromium	0.02	Lithium	0.01
Dysprosium						Hydrogen	NR

* Heterogeneous

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.002 µg/ml
MC — Major Component > 10 µg/ml
INT — Interference

Approved: M L Jacobs

TABLE F-55. SSMS ANALYSIS OF NEUTRAL LEACHATE OF CYCLONE DUST COMPOSITE OF RM-153 AND RM-154

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434

Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To:

Mr. Guy Crawford
Radian Corp.
P.O. Box 9948
Austin, TX 78766

Date: April 2, 1980

Analyst: J. Oldham

P. O. No.: 33499

Sample No.: 4670

NEUTRAL LEACHATE OF TE 4568

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

CONCENTRATION IN µg/ml

IAD No.: 97-E057-113-13

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	<0.01	Terbium		Ruthenium		Vanadium	0.006
Thorium	<0.02	Gadolinium		Molybdenum	0.02	Titanium	0.1
Bismuth		Europium		Niobium		Scandium	≤0.002
Lead	0.009	Samarium		Zirconium		Calcium	MC
Thallium		Neodymium		Yttrium		Potassium	MC
Mercury	NR	Praseodymium		Strontium	3	Chlorine	1
Gold		Cerium		Rubidium	0.007	Sulfur	MC
Platinum		Lanthanum		Bromine	0.07	Phosphorus	0.08
Iridium		Barium	0.9	Selenium	0.01	Silicon	0.2
Osmium		Cesium		Arsenic	0.02	Aluminum	>2
Rhenium		Iodine	0.004	Germanium		Magnesium	0.08
Tungsten		Tellurium		Gallium	0.06	Sodium	>5
Tantalum		Antimony		Zinc	0.01	Fluorine	≈0.07
Hafnium		Tin		Copper	0.006	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.008	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	≤0.003	Carbon	NR
Thulium		Silver	0.04	Iron	0.2	Boron	2
Erbium		Palladium		Manganese	<0.001	Beryllium	
Holmium		Rhodium		Chromium	0.01	Lithium	0.006
Dysprosium						Hydrogen	NR

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.002 µg/ml
MC — Major Component > 10 µg/ml
INT — Interference

Approved: M E Jacobs

TABLE F-56. SSMS ANALYSIS OF SOXHLET EXTRACTION SOLID RESIDUES COMPOSITE

COMMERCIAL TESTING & ENGINEERING CO.
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Paul N. Williams
Radian Corp.
8500 Shoal Creek Blvd.
P.O. Box 9948
Austin, TX 78766

Date: April 21, 1980

Analyst: J. Oldham

P. O. No.: 33924
Sample No.: 4967

IAD No.: 97-E261-113-02

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN PPM WEIGHT

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	8	Terbium	2	Ruthenium		Vanadium	68
Thorium	17	Gadolinium	4	Molybdenum	81	Titanium.	MC
Bismuth	7	Europium	1	Niobium	21	Scandium	2
Lead	740	Samarium	8	Zirconium	59	Calcium	MC
Thallium	4	Neodymium	10	Yttrium	30	Potassium	MC
Mercury	NR	Praseodymium	5	Strontium	MC	Chlorine	510
Gold		Cerium	71	Rubidium	79	Sulfur	MC
Platinum		Lanthanum	94	Bromine	3	Phosphorus	MC
Iridium		Barium	MC	Selenium	5	Silicon	MC
Osmium		Cesium	33	Arsenic	MC	Aluminum	MC
Rhenium		Iodine	9	Germanium	91	Magnesium	MC
Tungsten	20	Tellurium		Gallium	30	Sodium	MC
Tantalum	≤ 2	Antimony	71	Zinc	MC	Fluorine	≈800
Hafnium	2	Tin	66	Copper	120	Oxygen	NR
Lutetium	≤ 0.9	Indium	STD	Nickel	94	Nitrogen	NR
Ytterbium	≤ 4	Cadmium	7	Cobalt	2	Carbon	NR
Thulium	0.1	Silver	38	Iron	MC	Boron	85
Erbium	0.8	Palladium		Manganese	180	Beryllium	0.2
Holmium	3	Rhodium		Chromium	690	Lithium	6
Dysprosium	4					Hydrogen	NR

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.1 ppm
MC — Major Component >1000 ppm
INT — Interference

Approved: M J Jacobs

TABLE F-57. SSMS ANALYSIS OF SOXHLET EXTRACTION SOLVENT BLANK

COMMERCIAL TESTING & ENGINEERING CO.

Reply to
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Paul N. Williams
Radian Corp.
8500 Shoal Creek Blvd.
P.O. Box 9948
Austin, TX 78766

Date: April 21, 1980

Analyst: J. Oldham

P. O. No.: 33924

Sample No.: 4968

IAD No.: 97-E261-113-02

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN µg/ml

ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.	ELEMENT	CONC.
Uranium	<0.01	Terbium		Ruthenium		Vanadium	0.001
Thorium	<0.02	Gadolinium		Molybdenum	0.02	Titanium	0.01
Bismuth		Europium		Niobium		Scandium	≤0.002
Lead	0.02	Samarium		Zirconium	≤0.01	Calcium	0.6
Thallium		Neodymium		Yttrium		Potassium	0.5
Mercury	NR	Praseodymium		Strontium	0.03	Chlorine	0.1
Gold		Cerium		Rubidium		Sulfur	0.6
Platinum		Lanthanum		Bromine	0.02	Phosphorus	0.08
Iridium		Barium	9	Selenium		Silicon	MC
Osmium		Cesium		Arsenic		Aluminum	0.09
Rhenium		Iodine	≤0.004	Germanium	≤0.004	Magnesium	0.8
Tungsten		Tellurium		Gallium	≤0.004	Sodium	0.6
Tantalum		Antimony		Zinc	1	Fluorine	*=0.2
Hafnium		Tin		Copper	0.003	Oxygen	NR
Lutetium		Indium	STD	Nickel	0.003	Nitrogen	NR
Ytterbium		Cadmium		Cobalt	≤0.003	Carbon	NR
Thulium		Silver		Iron	2	Boron	*0.1
Erbium		Palladium		Manganese	0.002	Beryllium	
Holmium		Rhodium		Chromium	<0.001	Lithium	<0.001
Dysprosium						Hydrogen	NR

*Heterogeneous

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.002 µg/ml
MC — Major Component >10 µg/ml
INT — Interference

Approved: M S Jacobs

F.1.5.3 ICPES Analyses

ICPES analyses were performed on the following samples.

Sample Number	Sample Description
4549	Acid Impinger Solutions, RM-31, RM-32 (Composite)
4550	Base Impinger Solutions, RM-33, RM-34 (Composite)
4551	Charcoal, RM-35
4552	Persulfate Impinger Solution (1st in series), RM-36
4553	Persulfate Impinger Solution (2nd in series), RM-37
4554	Charcoal, RM-38
4555	Acid Solution Blank
4556	Base Solution Blank
4557	Charcoal Blank
4558	Persulfate Solution Blank
4559	Ash Pan Water, RM-18
4560	Ash Pan Water, RM-23
4561	Ash Pan Carry-Over Water, RM-4
4562	Ash Pan Water, RM-49
4563	Service Water, RM-5
4564	Gasifier Ash, RM-126
4565	Gasifier Ash, RM-147
4566	Lignite, RM-73
4567	Lignite, RM-77
4568	Cyclone Dust, RM-153, RM-154 (Composite)
4665	RCRA Leachate Blank
4666	Neutral Leachate Blank
4667	RCRA Leachate of TE 4658 (Gasifier Ash, RM-95, RM-98, RM-126, RM-147, RM-149, Composite)
4668	Neutral Leachate of TE 4658 (Gasifier Ash, RM-95, RM-98, Rm-126, RM-147, RM-149, Composite)
4669	RCRA Leachate of TE 4568 (Cyclone Dust, RM-153, RM-154 Composite)
4670	Neutral Leachate of TE 4568 (Cyclone Dust, RM-153, RM-154 Composite)

TABLE F-58. ICPES ELEMENTAL ANALYSES*

Sample	Cr	B	V	Ti	Ca	Mg	Na	K
1 BLANK	<0.001	0.040	<0.003	<0.005	<0.045	0.200	0.129	<0.042
2 QC-2	0.175	0.062	0.111	<0.005	<0.045	<0.034	0.092	<0.042
3 DI	0.001	<0.009	<0.003	<0.005	<0.045	<0.034	<0.006	<0.042
4 4549	0.005	0.058	<0.003	<0.005	0.134	<0.034	0.065	<0.042
5 DI	0.005	<0.009	<0.003	<0.005	<0.045	<0.034	<0.006	<0.042
6 4550	0.066	0.291	0.087	0.194	0.608	0.465	<0.006	4.747
7 DI	0.188	0.395	0.311	0.451	0.794	1.320	295.0	3.691
8 4551	0.213	0.398	0.314	0.502	0.880	1.559	2.576	4.189
9 DI	0.202	0.371	0.283	0.472	0.830	1.434	1.410	3.995
10 4552	0.174	0.295	0.217	0.401	0.700	1.191	0.889	3.446
11 DI	0.145	0.236	0.148	0.328	0.566	1.009	0.550	2.931
12 4553	0.127	0.216	0.097	0.280	0.482	0.827	0.332	2.549
7 DI	<0.001	<0.009	<0.003	<0.005	<0.045	<0.034	53.17	<0.042
8 4551	0.063	1.376	0.464	2.683	43.47	3.552	38.33	14.09
9 DI	<0.001	<0.009	<0.003	<0.005	<0.045	<0.034	0.116	<0.042
10 4552	0.023	3.196	<0.003	<0.005	32.86	0.086	3.174	4.505
11 DI	<0.001	<0.009	<0.003	<0.005	<0.045	0.074	0.126	<0.042
12 4553	<0.001	3.097	<0.003	<0.005	25.89	0.090	2.810	4.927
13 DI	<0.001	<0.009	<0.003	<0.005	<0.045	0.108	0.217	<0.042
14 4554	0.069	1.454	0.631	3.763	51.11	6.466	35.89	14.03
15 DI	<0.001	<0.009	<0.003	<0.005	<0.045	0.136	<0.006	<0.042
16 4555	<0.001	<0.009	<0.003	<0.005	<0.045	0.092	0.065	<0.042
17 DI	<0.001	<0.009	<0.003	<0.005	<0.045	0.110	<0.006	<0.042
18 4556	0.053	0.133	0.080	0.179	0.553	0.613	<0.006	4.914
19 DI	<0.001	<0.009	<0.003	<0.005	<0.045	0.169	25.72	<0.042

(Continued)

TABLE F-58. Continued

Sample	Cr	B	V	Ti	Ca	Mg	Na	K
20 4557	0.034	1.058	0.477	2.698	24.76	4.210	32.85	11.43
21 DI	<0.001	<0.009	<0.003	<0.005	<0.045	0.134	1.368	<0.042
22 4558	<0.001	3.190	<0.003	<0.005	22.98	0.106	3.039	4.914
23 DI	<0.001	<0.009	<0.003	<0.005	<0.045	.133	0.473	<0.042
24 4559	<0.001	3.211	0.006	0.048	127.1	1.677	585.3	73.77
25 DI	<0.001	<0.009	<0.003	<0.005	<0.045	0.164	0.192	<0.042
26 4560	<0.001	1.487	<0.003	<0.005	45.34	0.933	273.1	29.88
27 DI	<0.001	<0.009	<0.003	<0.005	<0.045	0.185	0.090	<0.042
28 4561	<0.001	0.518	<0.003	<0.005	37.94	5.174	73.93	7.602
29 DI	<0.001	<0.009	<0.003	<0.005	<0.045	0.157	<0.006	<0.042
30 4562	<0.001	3.174	<0.003	0.014	103.9	1.227	450.7	75.99
31 DI	<0.001	<0.009	<0.003	<0.005	<0.045	0.181	<0.006	<0.042
32 4563	<0.001	<0.009	<0.003	<0.005	5.452	0.950	6.025	1.447
33 DI	<0.001	<0.009	<0.003	<0.005	<0.045	0.193	<0.006	<0.042
34 BLANK	<0.001	<0.009	<0.003	<0.005	0.050	0.206	0.263	0.073
35 1632A7	30.57	51.32	43.46	1581	2109	890.6	731.6	3730
36 4564-1	<0.198	109.0	90.59	2247	208565	58198	24633	9617
37 4564-2	<0.199	108.1	89.96	2231	210235	58379	24963	9645
38 4565-1	<0.199	99.76	71.26	1739	212866	44569	23250	5634
39 4565-2	<0.199	80.53	71.10	1742	211335	44697	23652	5715
40 4566-1	<0.099	35.43	10.88	357.0	15262	3786	3785	1084
41 4566-2	<0.100	28.97	10.70	349.7	15144	3709	3707	1054
42 4567-1	2.100	34.74	15.16	275.6	14651	3811	3620	1366
43 4567-2	2.255	41.18	14.99	277.2	14382	3712	3545	1348

(Continued)

TABLE F-58. Continued

Sample	Cr	B	V	Ti	Ca	Mg	Na	K
44 4568-1	33.69	65.75	54.31	1187	58227	15938	15286	5583
45 4568-2	34.58	75.32	57.17	1210	60020	16399	15828	5771
46 163380	87.95	79.49	229.2	6351	63625	14493	2020	18860
47 BLANK	0.011	196.9	0.015	0.056	1.307	0.323	2.052	0.437
48 1632AB	33.60	210.1	45.17	1466	2135	768.7	673.1	3186
49 4564-3	54.69	679.4	113.0	2290	97968	24107	29238	8099
50 4564-4	54.99	<22.2	87.71	2286	99138	22213	29648	8045
51 4565-3	43.93	230.2	64.43	1962	99196	21677	28368	5213
52 4565-4	49.54	961.9	91.53	1976	99068	21779	27420	5315
52 4566-3	5.944	<3.19	17.86	337.2	12036	3149	4194	952.6
54 4566-4	5.037	<3.21	17.98	340.8	11843	3112	4198	961.7
55 4567-3	7.980	<2.87	23.52	283.8	12050	3070	4145	1273
56 4567-4	8.803	119.3	22.67	274.9	11842	2292	4149	1233
57 4568-3	69.07	469.3	100.6	1334	38496	10448	18428	5605
58 4568-4	71.67	694.9	71.82	1336	38547	10485	17613	5349
59 163381	166.4	517.1	257.8	6704	43213	10576	3661	14561

(Continued)

TABLE F-58. Continued

Sample	Fe	Mn	Al	Zn	Cu	Ni	Co	Mo
1 BLANK	<0.008	<0.001	0.056	<0.003	<0.001	<0.003	<0.006	0.002
2 QC-2	0.421	0.046	0.578	0.033	0.076	0.046	0.083	<0.002
3 DI	<0.008	<0.001	<0.050	<0.003	<0.001	<0.003	<0.006	<0.002
4 4549	0.073	0.003	<0.050	0.042	<0.001	0.007	<0.006	0.012
5 DI	<0.008	<0.001	<0.050	<0.003	<0.001	0.006	<0.006	0.003
6 4550	0.129	0.010	0.457	0.053	0.064	0.047	0.043	0.058
7 DI	0.096	0.026	1.130	0.061	0.169	0.127	0.123	0.120
8 4551	0.084	0.030	1.235	0.068	0.181	0.151	0.134	0.134
9 DI	0.077	0.029	1.160	0.066	0.169	0.144	0.129	0.127
10 4552	0.061	0.025	0.957	0.056	0.140	0.127	0.109	0.107
11 DI	0.047	0.022	0.720	0.047	0.111	0.110	0.092	0.087
12 4553	0.040	0.020	0.568	0.041	0.092	0.099	0.077	0.073
7 DI	<0.008	<0.001	<0.050	<0.003	<0.001	<0.003	<0.006	<0.002
8 4551	62.91	0.271	37.89	0.033	0.408	0.666	0.270	0.009
9 DI	<0.008	<0.001	<0.050	<0.003	<0.001	<0.003	<0.006	<0.002
10 4552	0.305	0.008	6.856	0.012	<0.001	0.033	<0.006	0.006
11 DI	<0.008	<0.001	<0.050	<0.003	<0.001	<0.003	<0.006	<0.002
12 4553	0.209	0.002	5.155	0.020	<0.001	<0.003	<0.006	<0.002
13 DI	<0.008	<0.001	<0.050	<0.003	<0.001	<0.003	<0.006	<0.002
14 4554	113.2	0.291	44.35	0.045	0.526	0.717	0.300	0.013
15 DI	<0.008	<0.001	<0.050	<0.003	<0.001	<0.003	<0.006	<0.002
16 4555	0.014	<0.001	<0.050	<0.003	<0.001	<0.003	<0.006	<0.002
17 DI	<0.008	<0.001	<0.050	<0.003	<0.001	<0.003	<0.006	<0.002
18 4556	0.104	0.008	0.461	0.025	0.054	0.035	0.028	0.055

(Continued)

TABLE F-58. Continued

Sample	Fe	Mn	Al	Zn	Cu	Ni	Co	Mo
19 DI	<0.008	<0.001	<0.050	<0.003	<0.001	<0.003	<0.006	<0.002
20 4557	26.71	0.210	26.51	0.029	0.446	0.466	0.188	0.016
21 DI	<0.008	<0.001	<0.050	<0.003	<0.001	<0.003	<0.006	<0.002
22 4558	0.052	0.001	4.639	<0.003	<0.001	0.006	<0.006	<0.002
23 DI	<0.008	<0.001	<0.050	<0.003	<0.001	<0.003	<0.006	<0.002
24 4559	3.457	0.097	3.952	0.015	0.011	0.010	<0.006	0.236
25 DI	<0.008	<0.001	<0.050	<0.003	<0.001	<0.003	<0.006	<0.002
26 4560	0.548	0.028	1.087	<0.003	0.004	<0.003	<0.006	0.108
27 DI	0.017	<0.001	<0.050	<0.003	<0.001	<0.003	<0.006	<0.002
28 4561	0.909	0.011	0.617	<0.003	<0.001	0.004	<0.006	0.024
29 DI	<0.008	<0.001	<0.050	<0.003	<0.001	<0.003	<0.006	<0.002
30 4562	1.892	0.051	2.218	0.004	0.006	0.007	<0.006	0.246
31 DI	<0.008	<0.001	<0.050	<0.003	<0.001	<0.003	<0.006	0.003
32 4563	0.213	0.022	0.147	<0.003	0.034	0.004	<0.006	0.005
33 DI	<0.008	<0.001	<0.050	<0.003	<0.001	<0.003	<0.006	<0.002
34 BLANK	0.030	<0.001	0.149	<0.003	<0.001	<0.003	<0.006	<0.002
35 1632A7	13090	25.12	26970	33.63	15.56	23.07	9.686	7.878
36 4564-1	103219	235.9	49959	39.06	44.64	25.24	17.95	23.04
37 4564-2	102918	233.0	49744	39.28	44.98	27.10	17.89	23.79
38 4565-1	78297	201.7	36924	28.67	42.20	21.11	14.46	21.07
39 4565-2	77723	201.8	36920	29.06	42.08	20.56	14.95	20.52
40 4566-1	24067	12.95	6281	8.338	6.842	4.008	2.913	4.825

(Continued)

TABLE F-58. Continued

Sample	Fe	Mn	Al	Zn	Cu	Ni	Co	Mo
41 4566-2	25027	12.65	6047	8.970	7.251	4.191	2.923	4.849
42 4567-1	18999	13.76	6133	9.125	8.179	6.748	3.170	5.815
43 4567-2	18413	13.47	6013	8.734	8.031	6.579	3.162	6.009
44 4568-1	21181	63.24	25965	71.49	29.89	19.64	9.452	14.39
45 4568-2	21630	65.04	26628	72.05	28.10	21.32	10.46	14.85
46 163380	92434	415.3	111513	228.8	126.0	94.71	57.38	55.94
47 BLANK	0.381	0.002	0.372	0.012	0.015	0.032	<0.006	0.020
48 1632A8	9357	26.55	23843	30.12	15.45	57.23	11.60	8.586
49 4564-3	56716	261.0	46092	35.43	42.09	101.8	33.58	33.08
50 4654-4	57422	266.9	45745	34.52	34.74	106.7	38.79	36.91
51 4565-3	46017	226.3	34102	21.46	30.39	65.10	29.13	30.89
52 4565-4	45794	227.2	33892	31.47	54.13	75.17	25.93	34.15
53 4566-3	17720	12.75	5678	8.711	8.250	15.42	5.004	6.514
54 4566-4	21106	12.79	5732	10.80	8.278	16.28	5.933	6.545
55 4567-3	15156	14.34	6085	9.761	9.717	14.54	6.707	7.715
56 4567-4	15231	13.97	5943	8.255	9.350	14.99	5.448	7.021
57 4568-3	15342	75.13	24001	13.19	39.29	53.76	35.42	31.18
58 4568-4	15474	75.41	23913	16.99	31.49	57.83	33.19	29.94
59 163381	55757	458.6	107367	189.9	129.3	279.2	87.04	79.99

(Continued)

TABLE F-58. Continued

Sample	Ba	Sample	Ba
1 BLANK	0.032	19 DI	0.027
2 QC-2	0.053	20 4557	1.234
3 DI	<0.001	21 DI	<0.001
4 4549	0.002	22 4558	0.024
5 DI	<0.001	13 DI	<0.001
6 4550	<0.001	24 4559	0.258
7 DI	<0.001	25 DI	<0.001
8 4551	<0.001	26 4560	0.123
9 DI	<0.001	27 DI	<0.001
10 4552	<0.001	28 4561	0.246
11 DI	<0.001	29 DI	<0.001
12 4553	<0.001	30 4562	0.208
7 DI	0.154	31 DI	<0.001
8 4551	0.844	32 4563	0.071
9 DI	<0.001	33 DI	<0.001
10 4552	0.060	34 BLANK	0.087
11 DI	<0.001	35 1632A7	107.0
12 4553	0.015	36 4564-1	3131
13 DI	0.031	37 4564-2	3052
14 4554	1.107	38 4565-1	2932
15 DI	<0.001	39 4565-2	3474
16 4555	0.085	40 4566-1	56.09
17 DI	<0.001	41 4566-2	38.46
18 4556	0.020	42 4567-1	35.17

(Continued)

TABLE F-58. Continued

Sample	Ba
43 4567-2	38.94
44 4568-1	1199
45 4568-2	2474
46 163380	2217
47 BLANK	0.283
48 1632A8	<0.313
49 4564-3	4210
50 4564-4	4132
51 4565-3	3956
52 4565-4	3915
53 4566-3	541.4
54 4566-4	586.8
55 4567-3	485.5
56 4567-4	481.3
57 4568-3	2435
58 4568-4	2413
59 163381	1503

*Results in µg/g of solid or µg/ml of liquid.
Date of Analysis 4/7/80

TABLE F-59. ICPES ELEMENTAL ANALYSES* OF LEACHATES

Sample	Cr	B	V	Ti	Ca	Mg	Na	K
1 BLANK	<0.001	<0.009	<0.003	<0.005	<0.045	<0.034	<0.006	<0.042
2 QC-2	0.174	<0.009	0.105	<0.005	<0.045	<0.034	0.204	<0.042
3 4665A	<0.001	<0.009	<0.003	<0.005	<0.045	<0.034	0.174	<0.042
4 4665B	<0.001	<0.009	<0.003	<0.005	<0.045	<0.034	<0.006	<0.042
5 4666	0.003	<0.009	<0.003	<0.005	<0.045	<0.034	<0.006	0.053
6 4667A	0.016	4.202	0.042	0.009	1423	23.37	136.7	15.10
7 4667B	0.015	4.295	0.048	0.005	1437	23.66	139.2	15.45
8 4668	0.027	1.983	0.034	0.037	155.2	0.467	131.7	13.22
9 4669A	0.066	3.722	0.095	0.145	558.4	4.034	225.3	9.873
10 4669B	0.065	3.861	0.101	0.139	616.1	4.096	231.4	10.07
11 4670	0.056	3.273	0.090	0.132	31.74	0.456	227.7	8.429

(Continued)

TABLE F-59. Continued

Sample	Fe	Mn	Al	Zn	Cu	Ni	Co	Mo
1 BLANK	<0.008	<0.001	<0.050	<0.003	<0.001	0.004	<0.006	<0.002
2 QC-2	0.419	0.048	0.450	0.032	0.075	0.069	0.079	<0.002
3 4665A	0.014	0.001	<0.050	0.011	<0.001	<0.003	<0.006	<0.002
4 4665B	<0.008	<0.001	<0.050	0.008	<0.001	<0.003	<0.006	<0.002
5 4666	<0.008	0.001	<0.050	<0.003	<0.001	<0.003	<0.006	<0.002
6 4667A	<0.008	0.003	<0.050	0.012	0.001	0.021	<0.006	0.061
7 4667B	<0.008	0.003	<0.050	0.013	<0.001	0.020	<0.006	0.055
8 4668	<0.008	0.003	7.639	0.012	0.012	0.040	0.009	0.069
9 4669A	0.021	0.010	3.619	0.026	0.050	0.067	0.038	0.132
10 4669B	0.024	0.010	10.12	0.027	0.049	0.066	0.036	0.107
11 4670	0.012	0.008	63.73	0.031	0.045	0.044	0.036	0.131

(Continued)

TABLE F-59. Continued

Sample	Ba	Si
1 BLANK	<0.001	<0.016
2 QC-2	<0.001	0.212
3 4665A	<0.001	<0.016
4 4665B	<0.001	<0.016
5 4666	<0.001	<0.016
6 4667A	0.230	5.833
7 4667B	0.240	5.910
8 4668	<0.001	0.192
9 4669A	<0.001	0.061
10 4669B	0.560	0.243
11 4670	<0.001	<0.016

*Results in µg/ml.

F.1.5.4 AAS Analyses

TABLE F-60. SODIUM AND MAGNESIUM ANALYSES BY ATOMIC ABSORPTION SPECTROSCOPY*

Sample No.	Sample Description	Conc. Na (ug/ml)	Conc. Mg (ug/ml)
4549	Acid Impinger Solutions, RM-31, RM-32 (Composite)	0.32	0.031
4550	Base Impinger Solutions, RM-33, RM-34 (Composite)	-	0.152
4552	Persulfate Impinger Solution (1st in series), RM-36	4.0	0.053
4553	Persulfate Impinger Solution (2nd in series), RM-37	3.6	0.057
4555	Acid Solution Blank	0.043	<0.03
4556	Base Solution Blank	-	0.15
4558	Persulfate Solution Blank	2.9	<0.03
4559	Ash Pan Water, RM-18	760	1.9
4560	Ash Pan Water, RM-23	360	0.99
4561	Ash Pan Carry-Over Water, RM-4	86	6.1
4562	Ash Pan Water, RM-49	590	1.3
4563	Service Water, RM-5	6.3	0.98

*Analyses performed due to Na and Mg contamination during ICPES analyses.

TABLE F-61. TRACE ELEMENT ANALYSES BY ATOMIC ABSORPTION SPECTROSCOPY

Radian Sample #	Sample Description	Sb (µg/1)	Ag (µg/1)	Hg (µg/1)	Se (µg/1)
4549	RM-31, 1st Acid Imp. RM-32, 2nd Acid Imp.	<3	38	<0.5	8
4550	RM-33, 1st Basic Imp. RM-33, 2nd Basic Imp.	17	53	0.5	22
4552	RM-36, 1st Persulfate	<3	74	4	10
4553	RM-37, 2nd Persulfate	<3	27	2	48
4555	Acid Blk	<3	5	<0.5	6
4556	Base Blk	23	37	<0.5	23
4558	Persulfate Blk	<3	6	<0.5	<5
4559	RM-18, Ash Pan Water	<3	23	<0.5	10
4560	RM-23, Ash Pan Water	<3	11	<0.5	<5
4561	RM-4, Ash Pan Carry-Over Water	<3	9	<0.5	<5
4562	RM-49, Ash Pan Water	<3	30	<0.5	6
4563	RM-5, Service Water	<3	1	<0.5	<5
4564	RM-126, Gasifier Ash	642, 491	56000	42	<1000
4565	RM-147, Gasifier Ash	1100, 1110	61000	61	<1000
4566	RM-73, Lignite	<500	21000	108	<500
4567	RM-77, Lignite	<500	25000	190	<500
4568	RM-153, RM-154, Cyclone Dust	710, 487	63000	19	1200

TABLE F-62. CONCENTRATIONS OF RCRA REGULATED ELEMENTAL CONTAMINANTS IN SOLID WASTE LEACHATES*

	4665 RCRA Blk	4666 Neutral Blk	4667 Gasifier Ash RCRA	4668 Gasifier Ash Neutral	4660 Cyclone Dust RCRA	4670 Cyclone Dust Neutral
As	<1	<1	33	2	3	4
Ba	<20	<20	680	120	300	390
Cd	<.5	<.5	<.5	<.5	<.5	<.5
Cr	<1	<1	<1	<1	<1	<1
Pb	<2	<2	<2	<2	<2	<2
Hg	<.5	<.5	<.5	<.5	<.5	<.5
Se	<1	<1	6	4	1	2
Ag	<.5	<.5	<.5	<.5	<.5	<.5

*All values reported as ug/l (ppb) and determined using Atomic Absorption Spectroscopy.

F.1.6 **Water Quality Analyses**

TABLE F-63. CONCENTRATIONS OF WATER QUALITY PARAMETERS IN LIQUID STREAMS AND GASIFIER ASH LEACHATES*

	Ash Pan Water Water Quality Range	Ash Pan Water Water Quality Average	Ash Pan Carry-Over Water Water Quality	Service Water Water Quality	Gasifier Ash RCRA Leachate Water Quality	Gasifier Ash Neutral Leachate Water Quality
pH	10.2 - 11.3	10.8	5.0	4.3	9.5	10.7
µmho/cm	1,550 - 3,620	2,690	415	47		
$S^=$	4.2 - 18	9.8	0.4	0.4		
$CN^=$		0.9		<0.2	<0.01	<0.01
$SCN^=$		<4		<4	<4	<4
NH_4^+		<30		<30	<2	<2
NO_3^-		<0.02		<0.02	23	23
$SO_4^=$	540 - 1,870	1,260		6.1	580	500
$PO^{4\equiv}$	<0.05 - 0.07	<0.06		<0.05	1.3	0.92
F^-	0.30 - 0.71	0.53		<0.05	1.03	0.26
Cl^-	48 - 110	78		14	45	19
TDS	1,250 - 3,050	2,250		52		
TSS	5.3 - 102	46		3.4		
Phenol	1.5 - 2.7	2.1		<0.05	<0.025	<0.025
TOC	7.5 - 15	11		7.3	474	2.7
COD	44 - 87	61		23	1,240	23
BOD	18 - 44	29		1.7	986	<1

*Concentrations in mg/liter.

F.2.0 ORGANIC ANALYSIS RESULTS

This section presents gravimetric and TCO screening data (Section F.2.1), infrared analysis results (Section F.2.2), LC analysis results (Section F.2.3), fugitive emission results (Section F.2.4), and the results of the analysis of RCRA leachates for pesticides and herbicides (Section F.2.5).

F.2.1 Gravimetric and TCO Screening Data

TABLE F-64. GRAVIMETRIC AND TCO SCREENING DATA

Sample I.D.	Sample Volume or Weight	Analytical Sample Vol. or Wt.	GRAV	TCO
Probe	712 ml	38 ml	692 mg TCO on GRAV 1.04 mg	13.5 mg
ESP	1415 ml	487 ml	16,900 mg TCO on GRAV 58.3 mg	82.7 mg
Filter	715 ml	12.6 ml	376 mg TCO on GRAV Below Blank	12.5 mg
Product Gas Aerosols		5.591 Nm^3	17,970 mg	109 mg
Condensate	660 ml	18 ml^{1,2}	9250 mg	8840 mg
		20 ml^{1,3}	160 mg	175 mg
Total			9410 mg	9020 mg
Condenser Rinse	580 ml		2480 mg	1360 mg
XAD-2 Resin	170 g	84.4 g	2280 mg	6500 mg
Product Gas Vapors		3.980 Nm^3	14,200 mg	16,900 mg

(Continued)

TABLE F-64. Continued

Sample I.D.	Sample Volume or Weight	Analytical Sample Vol. or Wt.	GRAV	TCO
Ash Pan Water:				
RM-18	3000 ml	10 ml	2.0 µg/ml[2]	2.66 µg/ml[4]
	3000 ml	10 ml	0.67 µg/ml[3]	
RM-23	3000 ml	10 ml	5.0 µg/ml[2]	1.78 µg/ml[4]
	3000 ml	10 ml	0.33 µg/ml[3]	
RM-49	2500 ml	10 ml	0.80 µg/ml[2]	3.3 µg/ml[4]
	2500 ml	10 ml	0.40 µg/ml[3]	
Average Totals			3.1 µg/ml[4]	2.6 µg/ml[4]
Service Water	3000 ml	10 ml	Below Blank[2]	0.2 µg/ml[4]
			0.33 µg/ml[3]	
Total			0.33 µg/ml	0.2 µg/ml
Gasifier Ash	650 mg			
Not Ground		20.8 ml	180 µg/g	3.32 µg/g
Ground		10 ml	60.0 µg/g	1.62 µg/g
Total			240 µg/g	4.94 µg/g
Cyclone Dust	150 g	52.6 ml	5.44 mg/g	0.144 mg/g

[1] 5% of total sample extracted.
[2] CH_2Cl_2 and Et_2O extracts, pH 2.
[3] CH_2Cl_2 and Et_2O extracts, pH 12.
[4] All extracts combined.

TABLE F-65. PRODUCT GAS AEROSOLS--TCO AND GRAV DATA OF PROBE, ESP AND FILTER

	GRAV ($\mu g/Nm^3$)	TCO ($\mu g/Nm^3$)
Probe	(1.24 E5)	(2.41 E3)
ESP	(3.02 E6)	(1.48 E4)
Filter	(6.73 E4)	(2.24 E3)

TABLE F-66. PRODUCT GAS AEROSOLS--TCO AND GRAV DATA AND PARTICULATE AND ORGANIC LOADINGS

Gas Sample Volume:	5.591 Nm^3
Particulate Collected:	2.66241 grams
Particulate Loading:	4.76 E5 $\mu g/Nm^3$ (0.215 grains/SCF)
TCO:	2.31 E4 $\mu g/Nm^3$
GRAV:	3.24 E6 $\mu g/Nm^3$
Organic Loading:	3.26 E6 $\mu g/Nm^3$ (1.46 grains/SCF)
Total Loading:	3.74 E6 $\mu g/Nm^3$ (1.48 grains/SCF)

TABLE F-67. PRODUCT GAS VAPORS—TCO AND GRAV DATA AND ORGANIC LOADING

Gas Sample Volume*:	3.98 Nm³
TCO:	3.64 E6 μg/Nm³
GRAV:	2.19 E6 μg/Nm³
Organic Loading:	5.83 E6 μg/Nm³ (2.63 grains/SCF)

*Organic module sampling volume.

TABLE F-68. ASH PAN WATER AND SERVICE WATER ORGANIC LOADINGS

	TCO (μg/1)	GRAV (μg/1)	Organic Loading (μg/1)
Ash Pan Water			
12/13 1930 hours	2.7 E3	2.7 E3	5.4 E3
12/14 0000 hours	1.8 E3	5.3 E3	7.1 E3
12/14 0640 hours	3.3 E3	1.2 E3	4.5 E3
Service Water	2.0 E2	3.3 E2	5.3 E2

F.2.2 Infrared Analysis Results

TABLE F-69. INFRARED ANALYSIS — PRODUCT GAS AEROSOLS

Sample: Product Gas Aerosols
ESP Solids and Rinse—$MeCl_2$ Extract

Wave Number (cm^{-1})	Intensity	Assignment
3470–3140	M	–OH, –NH
3060	W	Aromatic CH
2960–2850	S	Aliphatic CH
1960	W	Aromatic Overtones
1710–1655	M	Carbonyl
1605	M	Aromatics
1515	W	Aromatics
1465,1455	M	Aliphatics
1380	W	Aliphatics
1265	M	$MeCl_2$ Residual
1240–1110	M	Esters, Ethers, Heterocyclic –O, –N, Phenols
945	W	Cyclic Anhydrides, Acids
805	W	Aromatic Substitution
740,700	M	$MeCl_2$ Residual

Comments: Strongly aromatic. Phenols present. Anhydrides, ethers probable.

Sample: Product Gas Aerosols
Probe and Nozzle Solids and Rinse—$MeCl_2$ Extract

Wave Number (cm^{-1})	Intensity	Assignment
3500–3190	S	–OH, –NH
3055	W	Aromatic CH
2950–2920	S	Aliphatic CH
2850	S	Aliphatic CH
1685	M	Carbonyl
1603	M	Aromatics, Amines, Carboxylate
1510	W	Aromatics
1460	M	Aliphatics
1375	M	Aliphatics
1300–1150	M	Phenols, Amines, Heterocyclic –N, –O, Ethers, $MeCl_2$
1030	W	Aliphatic C–O
960	W	Alkenes, Acids
890–840	M	Aromatic Substitution
810	M	Aromatic Substitution
745,700	M	Aromatic Substitution, $MeCl_2$

Comments: Strongly aromatic. Phenols and amines. Possibly some heterocyclic –N, –O. Moisture present.

(Continued)

TABLE F-69. Continued

Sample: Product Gas Aerosols
Probe and Nozzle Solids and Rinse—ET_2O Extract

Wave Number (cm^{-1})	Intensity	Assignment
3620–3140	M	-OH
2955–2850	S	Aliphatic CH
1705–1635	M	H_2O
1610	M	Aromatics
1510	W	Aromatics
1460	M	Aliphatics
1380	M	Aliphatics

Comments: Weak spectrum. Predominantly aliphatics. Some moisture indicated.

Sample: Product Gas Aerosols
ESP Solids and Rinse—ET_2O Extract

Wave Number (cm^{-1})	Intensity	Assignment
3480–3140	M	-OH, -NH
2960–2850	S	Aliphatic CH
1700	M	Carbonyl
1605	M	Aromatics, Carboxylate, Amines
1515	W	Aromatics
1475	M	Aromatics
1460	M	Aliphatics
1380	W	Aliphatics
1355	W	Phenols, Acids
1300–1200	M	Amines
1300–1200	M	Esters, Acids, Ethers
1190	W	Aromatic Ethers, Phenols
1040	W	Alcoholic C-O
840–800	W	Aromatic Substitution
750	W	Aromatic Substitution
705,715	W	$MeCl_2$

Comments: Phenols present. Stronger carbonyl band than 51 and 56 or 2, 57, 63. Esters and carboxylic acids probable. Possibly amines.

(Continued)

TABLE F-69. Continued

Sample: Product Gas Aerosols
Filters and Rinse--MeCl$_2$ Extract

Wave Number (cm^{-1})	Intensity	Assignment
3560-3140	M	-OH, -NH
3050	W	Aromatic CH
2960-2850	S	Aliphatic CH
2300	W	Isocyanates
1700-1650	M	Carbonyl
1600	M	Aromatics
1510	W	Aromatics
1460	M	Aliphatics
1380	M	Aliphatics
1300-1150	M	Heterocyclic -O, -N, Acids, Esters, Phenols, MeCl$_2$
1035	W	Alcoholic C-O
880	W	Aromatic Substitution
800	W	Aromatic Substitution
730,690	S	MeCl$_2$

Comments: Predominantly aromatic isocyanates present. Phenols and carboyxylic acids probable. Carbonyl band not as strong as in ESP spectrum. Heterocyclics possible.

Sample: Product Gas Aerosols
Filters and Rinse--ET$_2$O Extract

Wave Number (cm^{-1})	Intensity	Assignment
3620-3130	S	-OH
2970-2850	S	Aliphatic CH
1[illegible]30-1530	M	H_2O
1465	M	Aliphatics

(Continued)

TABLE F-69. Continued

Sample: Product Gas Aerosols
Composite Sample

Wave Number (cm^{-1})	Intensity	Assignment
3350-3175	M	-OH, -NH
3060	W	Aromatic CH
2930	S	Aliphatic CH
2850	S	Aliphatic CH
2310	W	Isocyanates, Alkynes
1670-1705	M	Carbonyls
1605	M	Aromatics, Amines, Carbonyls
1515	W	Aromatics
1460	M	Aliphatic CH
1380	W	Aliphatic CH Branching
1265	M	$MeCl_2$ Contamination, Esters, Ethers, Heterocyclic O or N
1035	W	Ethers, Alcohols, Phenols
895,815	W	Aromatic Substitution
735	S	Aromatic Substitution
700	M	Aromatic Substitution, $MeCl_2$ Contamination

Comments: Strongly aromatic. Little carbonyl character. Esters present. Aliphatic branching indicated.

TABLE F-70. INFRARED ANALYSIS -- PRODUCT GAS VAPORS

Sample: Product Gas Vapors
XAD-2 Resin Blank

Wave Number (cm^{-1})	Intensity	Assignment
3480-3120	M	-OH
3060	W	Aromatic CH
2950-2850	S	Aliphatic CH
1730	S	Carbonyl
1650-1600	M	H_2O, Aromatics, Carboxylate
1465	M	Aliphatics
1380	W	Aliphatics
1265	M	$MeCl_2$, Ethers, Acids
1160	W	Esters, Ketones
1110	W	Aliphatic Ethers
1060	W	Aromatic Ethers
740	W	$MeCl_2$
700	W	$MeCl_2$
670	W	Amines, Alkenes

Comments: Strongly aliphatic. Strong carbonyl character. Esters, acids present. Ethers possible.

Sample: Product Gas Vapors
Condenser $MeCl_2$ Rinse

Wave Number (cm^{-1})	Intensity	Assignment
3530-3130	M	-OH, -NH
3050-3000	W	Aromatic CH
2960-2850	S	Aliphatic CH
1690	M	Carbonyl
1600	M	Aromatics
1515	M	Aromatics
1465-1445	M	Aliphatics
1380	W	Aliphatics
1275	M	$MeCl_2$
1240-1185	M	Esters, Ethers — C-O stretch
815	M	Aromatic Substitution
750	M	$MeCl_2$ Residual, Aromatic Substitution
695	W	$MeCl_2$ Residual, Aromatic Substitution

Comments: Strongly aromatic. Phenols present. Esters, ethers probable. Heterocyclic -O, -N possible.

(Continued)

TABLE F-70. Continued

Sample: Product Gas Vapors
Condensate, pH=12 Extract

Wave Number (cm^{-1})	Intensity	Assignment
3560-3140	S	-OH, -NH
2960-2850	M	Aliphatic CH
1600	S	Aromatics
1515	M	Aromatics
1470-1320	M	H_2O
1260	M	$MeCl_2$
1190-1090	M	H_2O
750	M	$MeCl_2$

Comments: Some indication of aromatics. Wet sample. $MeCl_2$ contamination.

Sample: Product Gas Vapors
Condensate, pH=2 Extract

Wave Number (cm^{-1})	Intensity	Assignment
3420-3320	S	-OH
3050	W	Aromatic CH
2960-2850	S	Aliphatic CH
1640-1660	M	Carbonyl
1600	M	Aromatics
1510	M	Aromatics
1450,1460	M	Aliphatics
1375	W	Aliphatics
1360	W	Phenols
1270	M	$MeCl_2$
1250	M	Aromatic Ethers
1185	M	Phenols, Esters
1110	W	Alcohols, Aliphatic Ethers, Aromatic Substitution
1090	W	Alcohols, Aliphatic Ethers, Aromatic Substitution
1025	W	Aliphatic C-O
940	W	Aliphatics, S-Compounds
800	W	Aromatic Substitution
765,745	M	$MeCl_2$

Comments: Predominantly aromatic. Phenols present. Ethers, esters probable.

TABLE F-71. INFRARED ANALYSIS -- CYCLONE DUST COMPOSITE

Sample: Cyclone Dust Composite

Wave Number (cm^{-1})	Intensity	Assignment
3460-3130	M	-OH, -NH
3150	W	Aromatic CH (shoulder)
2950-2850	S	Aliphatic CH
1690	M	Carbonyl
1600	M	Aromatics, Amines
1515	W	Aromatics
1405	M	Aliphatics
1380	W	Aliphatic Branching
1265	W	$MeCl_3$
1350-1320	W	Amines, Ethers
1030	W	Aliphatic C-O
870-840	W	Aromatic Substitution, Amines
805	W	Aromatic Substitution, Amines
730,690	M,W	$MeCl_3$

Comments: Predominantly aliphatic. Phenosl and amines possible.

TABLE F-72. INFRARED ANALYSIS -- GASIFIER ASH

Sample: Gasifier Ash (not ground)

Wave Number (cm^{-1})	Intensity	Assignment
3600–3220	M	-OH, -NH
2945–2850	S	Aliphatic CH
1750–1580	M	H_2O, Carbonyl
1460	M	Aliphatics
1380	W	Aliphatic CH
1300–1225	W	H_2O, Esters
1170	W	H_2O

Comments: No aromatics. Predominantly aliphatics with branching. Water present. Esters possible, but somewhat obscured by water.

Sample: Gasifier Ash (ground)

Wave Number (cm^{-1})	Intensity	Assignment
3520–3220	M	-OH, -NH
2960–2850	S	Aliphatic CH
1730	M	Carbonyl
1605	W	Aromatic
1515	W	Aromatic (shoulder)
1460	M	Aliphatic
1380	W	Aliphatic Branching
1280–1265	M	Esters, Ketones, Phenols
730	W	Aromatic Substitution
470	W	Aromatic Substitution, Sulfate

Comments: Predominantly aliphatic. Some aromatics, esters and ketones probable. Possibly some phenols and sulfate. More material present in this sample than in gasifier ash, not ground.

TABLE F-73. INFRARED ANALYSIS — ASH PAN WATER

Sample: Ash Pan Water -- 12/13, 1930 Hours, pH=2 Extract

Wave Number (cm⁻¹)	Intensity	Assignment
4000-3120	S	-OH, -NH
2930	S	Aliphatic CH
2850	M	Aliphatic CH
1705	S	Carbonyls
1615	M	Aromatics
1515	M	Aromatics
1460	M	Aliphatics
1380	W	Aliphatics
1265	M	Esters, $MeCl_2$ Contamination
1220	M	Ethers, Esters, Phenols
1120	W	Alcohols
1035	W	Aromatic Ethers

Comments: Phenols. Strong carbonyl character. Wet sample.

Sample: Ash Pan Water — 12/13, 1930 Hours, pH=12 Extract

Wave Number (cm⁻¹)	Intensity	Assignment
3620-3140	S	-OH, -NH
2960,2920	S	Aliphatic CH
2850	S	Aliphatic CH
1680-1580	M	H_2O
1220-1060	M	H_2O
1040	M	Alcoholic C-O

(Continued)

TABLE F-73. Continued

Sample: Ash Pan Water -- 12/14, 0000 Hours, pH=2 Extract

Wave Number (cm^{-1})	Intensity	Assignment
3410-3170	S	-OH, -NH (shoulder)
3060	W	Aromatic CH (shoulder)
2920-2850	S	Aliphalic CH
1710	S	Carbonyls
1600	M	Aromatics
1510	W	Aromatics
1455	S	Aliphatics
1375	M	Aliphatics
1280-1100	M	Phenols, Ethers, Acids
1082	W	Ethers, Alcohols, C-O stretch
1070	W	Ethers, Alcohols, C-O stretch
1040	W	Alcoholic C-O
875,855	W	Aromatic Substitution
745,720	W	$MeCl_2$
580	W	Alkenes, S-Compounds

Comments: Strong carbonyl band. Predominantly aliphatic. Alcohols and acids most likely. Esters and ethers also possible.

Sample: Ash Pan Water -- 12/14, 0000 Hours, pH=12 Extract

Wave Number (cm^{-1})	Intensity	Assignment
3580-3160	S	-OH, -NH
2945-2850	S	Aliphatic CH
1760-1060	S	H_2O
1020	W	Alcoholic C-O

(Continued)

TABLE F-73. Continued

Sample: Ash Pan Water -- 12/14, 0640 Hours, pH=2 Extract

Wave Number (cm^{-1})	Intensity	Assignment
3540-3190	S	-OH, -NH
2960,2920	S	Aliphatic CH
2870,2850	M	Aliphatic CH
1700	S	Carbonyls
1615	S	Aromatic Ring
1515	S	Aromatics
1455	S	Aliphatics
1395-1350	M	Aliphatics
1270	M	$MeCl_2$ Contamination, Phenols
1220	M	Esters, Phenols
1120	W	Phenols, Ethers, Amines
1045	W	Aromatic Ethers
835	M	Aromatic Substitution
815	M	Aromatic Substitution
735	M	Aromatic Substitution

Comments: Phenols probable. Carbonyls. Not much aliphatic character.

Sample: Ash Pan Water — 12/14, 0640 Hours, pH=12 Extract

Wave Number (cm^{-1})	Intensity	Assignment
3650-3200	S	-OH, -NH
2960	M	Aliphatic CH
2920	S	Aliphatic CH
2850	M	Aliphatic CH
1800-1390	S	H_2O Vapor
1020	M	Alcoholic C-O

TABLE F-74. INFRARED ANALYSIS -- SERVICE WATER

Sample: Service Water, pH=2 Extract

Wave Number (cm^{-1})	Intensity	Assignment
3600-3150	M	-OH, -NH
2960-2850	M	Aliphatic CH
1740-1710	S	Carbonyl
1465	W	Aliphatics
1385	W	Aliphatics
1170	W	H_2O

Sample: Service Water, pH=12 Extract

Wave Number (cm^{-1})	Intensity	Assignment
3660-3140	M	-OH, -NH
2960-2850	S	Aliphatic CH
1800-1360	S	H_2O
1020	M	Alcoholic C-O

F.2.3 LC Analysis Results

TABLE F-75. LC ANALYSIS RESULTS -- PRODUCT GAS AEROSOLS

Original Sample Volume or Mass: 5.591 Nm^3 [0.53% (0.0296 Nm^3) of extract taken for LC]

	TCO mg	GRAV mg	TCO + GRAV Total mg	Concentration mg/Nm^3
Total Sample[1]	129	18100	18200	3260
Taken for LC[2]	0.684	95.9	96.6	3260
Recovered[3]	0.071	95.8	95.9	3240
% Recovered	10.4%	99.9%	99.3%	99.4%

	TCO in mg				GRAV in mg					
Fraction	Found in Fraction	Blank	Cor-rected	Total[4]	Found in Fraction	Blank	Cor-rected	Total[4]	TCO + GRAV Total mg	Concentration mg/Nm^3
1	.033	0.00	.003	6.24	13.2	0.0	13.2	2490	2500	447
2	.008	.003	.005	.945	2.8	0.2	2.6	491	492	88.0
3	.002	.002	.000	.000	9.8	0.0	9.8	1850	1850	331
4	.005	.002	.003	.567	11.8	0.0	11.8	2230	2230	399
5	.002	.004	0	0	11.4	0.2	11.2	2120	2120	379
6	.036	.005	.031	5.86	39.4	0.0	39.4	7450	7460	1330
7	.0009	.0005	.0004	.0756	8.0	0.2	7.8	1470	1470	263
Sum	.087	.017	.072	13.7	96.4	0.6	95.8	18100	18100	3240

[1] Quantity in entire sample, determined before LC

[2] Portion of whole sample used for LC, actual mg

[3] Quantity recovered from LC column, actual mg

[4] Total mg computed back to total sample

TABLE F-76. LC ANALYSIS RESULTS -- PRODUCT GAS VAPORS

Original Sample Volume or Mass: 3.98 Nm^3 [0.294% (0.0117 Nm^3) of extract taken for LC]

	TCO mg	GRAV mg	TCO + GRAV Total mg	Concentration mg/Nm^3
Total Sample[1]	14,500	8700	23,200	5830
Taken for LC[2]	42.6	25.6	68.2	5830
Recovered[3]	32.2	29.0	61.2	5230
% Recovered	75.6%	113%	89.7%	89.7%

	TCO in mg				GRAV in mg					
Fraction	Found in Fraction	Blank	Cor-rected	Total[4]	Found in Fraction	Blank	Cor-rected	Total[4]	TCO + GRAV Total mg	Concentration mg/Nm^3
1	10.1	0.00	10.1	3430	4.0	0.0	4.0	1360	4790	1200
2	1.72	.003	1.72	585	1.8	0.2	1.6	544	1130	284
3	.663	.002	.661	225	2.0	0.	2.0	680	905	227
4	2.77	.002	2.77	942	2.6	0.0	2.6	884	1830	460
5	9.67	.0036	9.67	3290	3.0	0.2	2.8	952	4240	1060
6	6.65	.0049	6.64	2260	13.2	0.0	13.2	4490	6750	1700
7	0.689	.0005	.668	234	3.0	0.2	2.8	952	1190	299
Sum	32.3	.016	32.2	11000	29.6	0.6	29.0	9860	20900	5250

[1] Quantity in entire sample, determined before LC
[2] Portion of whole sample used for LC, actual mg
[3] Quantity recovered from LC column, actual mg
[4] Total mg computed back to total sample

TABLE F-77. LC ANALYSIS RESULTS -- GASIFIER ASH

Original Sample Volume or Mass: 650 g [36.8% (239 g) of extract taken for LC]

	TCO mg	GRAV mg	TCO + GRAV Total mg	Concentration mg/kg
Total Sample[1]	2.28	152	154	237
Taken for LC[2]	0.839	55.9	56.7	107
Recovered[3]	0.902	119	120	185
% Recovered	108%	213%	212%	173%

Fraction	TCO in mg				GRAV in mg				TCO + GRAV Total mg	Concentration mg/kg
	Found in Fraction	Blank	Cor- rected	Total[4]	Found in Fraction	Blank	Cor- rected	Total[4]		
1	.125	0.0	.125	.34	30.0	0.0	30.0	81.6	81.9	126
2	.115	.003	.112	.305	10.6	0.2	10.4	28.3	28.6	44
3	.134	.002	.132	.359	3.2	0.0	3.2	8.70	9.06	13.9
4	.004	.002	.002	.005	1.8	0.0	1.8	4.90	4.90	7.54
5	.003	.004	0	0	1.0	0.2	0.8	2.18	2.18	3.35
6	.031	.005	.026	.070	4.0	0.0	4.0	10.9	11.0	16.9
7	.010	.001	.009	.024	3.6	0.2	3.4	9.25	9.27	14.3
Sum	.422	.017	.405	1.10	54.2	0.6	53.6	146	147	226

[1] Quantity in entire sample, determined before LC

[2] Portion of whole sample used for LC, actual mg

[3] Quantity recovered from LC column, actual mg

[4] Total mg computed back to total sample

TABLE F-78. LC ANALYSIS RESULTS -- CYCLONE DUST

Original Sample Volume or Mass: 150 grams [11.4% (17.1 g) of extract taken for LC]

	TCO mg	GRAV mg	TCO + GRAV Total mg	Concentration mg/kg
Total Sample[1]	22.4	821	843	5620
Taken for LC[2]	2.55	93.6	96.2	5630
Recovered[3]	2.05	89.6	91.6	5360
% Recovered	80.4%	95.7%	95.2%	95.2%

	TCO in mg				GRAV in mg					
Fraction	Found in Fraction	Blank	Cor-rected	Total[4]	Found in Fraction	Blank	Cor-rected	Total[4]	TCO + GRAV Total mg	Concentration mg/kg
1	1.30	0.0	1.30	11.4	8.8	0.0	8.8	77.2	88.6	591
2	.284	.003	.281	2.46	4.4	0.2	4.2	36.8	39.3	262
3	.060	.002	.058	.509	14.2	0.0	14.2	125	126	840
4	.024	.002	.022	.193	11.0	0.0	11.0	96.5	96.7	645
5	.070	.004	.066	.579	9.2	0.2	9.0	78.9	79.5	530
6	.330	.005	.325	2.85	37.0	0.0	37.0	325	328	2190
7	.002	.0005	.002	.018	5.6	0.2	5.4	47.4	47.4	316
Sum	2.07	.016	2.05	18.0	90.2	0.6	89.6	787	806	5370

[1] Quantity in entire sample, determined before LC
[2] Portion of whole sample used for LC, actual mg
[3] Quantity recovered from LC column, actual mg
[4] Total mg computed back to total sample

TABLE F-79. LC ANALYSIS RESULTS -- ASH PAN WATER COMPOSITE

Original Sample Volume or Mass: 9000 mg [60% (5.4 1) of extract taken for LC]

	TCO mg	GRAV mg	TCO + GRAV Total mg	Concentration mg/L
Total Sample[1]	22.4	39.6	62.0	11.5
Taken for LC[2]	8.05	23.7	31.8	9.8
Recovered[3]	7.83	16.4	24.2	7.5
% Recovered	97.3%	69.2%	76.1%	76.5%

Fraction	TCO in mg Found in Fraction	Blank	Cor-rected	Total[4]	GRAV in mg Found in Fraction	Blank	Cor-rected	Total[4]	TCO + GRAV Total mg	Concentration mg/L
1	.105	0.00	.105	.292	5.0	0.0	5.0	13.9	14.2	1.6
2	.328	.003	.325	.903	0.2	0.2	0.0	0.0	0.9	0.10
3	.069	.002	.067	.186	0.4	0.0	0.4	1.1	1.3	0.14
4	.145	.002	.143	.397	0.6	0.0	0.6	1.7	2.1	0.23
5	.909	.0036	.905	2.52	0.8	0.2	0.6	1.7	4.2	0.47
6	6.28	.0049	6.28	17.4	6.8	0.0	6.8	18.9	36.3	4.0
7	.0025	.0005	.002	.0056	3.2	0.2	3.0	8.3	8.3	0.92
Sum	7.84	.016	7.83	21.7	17.0	0.6	16.4	45.6	24.2	7.5

[1] Quantity in entire sample, determined before LC

[2] Portion of whole sample used for LC, actual mg

[3] Quantity recovered from LC column, actual mg

[4] Total mg computed back to total sample

TABLE F-80. PRODUCT GAS AEROSOLS—TCO, GRAV, AND ORGANIC LOADING DATA

	TCO		GRAV		ORGANIC LOADING	
	μg/g	(μg/Nm^3)	μg/g	(μg/Nm^3)	μg/g	(μg/Nm^3)
Whole Composite	6.2 E3	(2.3 E4)	8.6 E5	(3.2 E6)	8.8 E5	(3.3 E6)
Composite						
LC 1	2.9 E2	(1.1 E3)	1.2 E5	(4.4 E5)	1.2 E5	(4.4 E5)
LC 2	4.6 E1	(1.7 E2)	2.4 E4	(8.8 E4)	2.4 E4	(8.8 E4)
LC 3	0	(0)	8.8 E4	(3.3 E5)	8.8 E4	(3.3 E5)
LC 4	2.7 E1	(1.0 E2)	1.1 E5	(4.0 E5)	1.1 E5	(4.0 E5)
LC 5	0	(0)	1.0 E5	(3.8 E5)	1.0 E5	(3.8 E5)
LC 6	2.7 E2	(1.0 E3)	3.5 E5	(1.3 E6)	3.5 E5	(1.3 E6)
LC 7	3.8 E4	(1.4 E1)	7.0 E4	(2.6 E5)	7.0 E4	(2.6 E5)

Percent Recovery: 96.9

TABLE F-81. PRODUCT GAS VAPORS—TCO, GRAV, AND ORGANIC LOADING DATA

	TCO (μg/Nm^3)	GRAV (μg/Nm^3)	Organic Loading (μg/Nm^3)
Whole Composite	3.6 E6	2.2 E6	5.8 E6
Composite			
LC 1	8.6 E5	3.4 E5	1.2 E6
LC 2	1.5 E5	1.4 E5	2.8 E5
LC 3	5.7 E4	1.7 E5	2.3 E5
LC 4	2.4 E5	2.2 E5	4.6 E5
LC 5	8.3 E5	2.4 E5	1.1 E6
LC 6	5.7 E5	1.1 E6	1.7 E6
LC 7	5.9 E4	2.4 E5	3.0 E5

Percent Recovery: 90.9

TABLE F-82. GASIFIER ASH -- TCO, GRAV AND ORGANIC LOADING DATA

	TCO (ug/g)	GRAV (ug/g)	Organic Loading (ug/g)
Whole Sample	3.5	2.3 E2	2.4 E2
LC1	5.2 E-1	1.3 E2	1.3 E2
LC2	4.7 E-1	4.4 E1	4.4 E1
LC3	5.5 E-1	1.3 E1	1.4 E1
LC4	7.7 E-3	7.5	7.5
LC5	0	3.4	3.4
LC6	1.1 E-1	1.7 E1	1.7 E1
LC7	3.7 E-2	1.4 E1	1.4 E1

Percent Recovery: 95.8

TABLE F-83. COMPOSITE CYCLONE DUST -- TCO, GRAV AND ORGANIC LOADING DATA

	TCO (ug/g)	GRAV (ug/g)	Organic Loading (ug/g)
Whole Sample	1.5 E2	5.5 E3	5.6 E3
LC1	7.6 E1	5.1 E2	5.9 E2
LC2	1.6 E1	2.5 E2	2.6 E2
LC3	3.4	8.3 E2	8.4 E2
LC4	1.3	6.4 E2	6.4 E2
LC5	3.9	5.3 E2	5.3 E2
LC6	1.9 E1	2.2 E3	2.2 E3
LC7	1.2 E-1	3.2 E2	3.2 E2

Percent Recovery: 96.1

TABLE F-84. COMPOSITE ASH PAN WATER AND LC FRACTIONS ORGANIC LOADING

	TCO (µg/1)	GRAV (µg/1)	Organic Loading (µg/1)
Whole Composite	4.1 E3	7.3 E3	1.2 E4
Composite			
LC1	3.2 E1	1.5 E3	1.6 E3
LC2	1.0 E2	0	1.0 E2
LC3	2.1 E1	1.2 E2	1.4 E2
LC4	4.4 E1	1.9 E2	2.3 E2
LC5	2.8 E2	1.9 E2	4.7 E2
LC6	1.9 E3	2.1 E3	4.0 E3
LC7	6.2 E-1	9.2 E2	9.2 E2
Percent Recovery: 62.2			
Service Water	2.0 E2	3.3 E2	5.3 E2

TABLE F-85. PERCENTAGE OF ORGANIC MATERIAL IN LC FRACTIONS

	Product Gas: Particulates, Tars and Oils	Product Gas: Gas and Vapors	Gasifier Ash	Cyclone Dust	Ash Pan Water
LC 1	13.8% (2)	22.8% (2)	56.5% (1)	11.0%	21.5% (2)
LC 2	2.8%	5.3%	19.1% (2)	4.8%	1.3%
LC 3	10.3%	4.4%	6.1%	15.6% (2)	1.9%
LC 4	12.5% (3)	8.7%	3.3%	11.9% (3)	3.1%
LC 5	11.9%	20.9% (3)	1.5%	9.8%	6.3%
LC 6	40.6% (1)	32.2% (1)	7.4% (3)	40.9% (1)	53.6% (1)
LC 7	8.1%	5.7%	6.1%	6.0%	12.3% (3)

F.2.4 Fugitive Emission Results

TABLE F-86. PRODUCT GAS BTX GAS FRACTION ANALYSIS

		Charcoal Tube #1 1825-1846 12/13/79 1020 dry Ncc			Charcoal Tube #2 1848-2000 2870 dry Ncc		
Front:	Benzene	203 µg			898 µg		
	Toluene	150 µg			413 µg		
	Xylene	204 µg			291 µg		
Back:	Benzene	<1 µg			2.5 µg		
	Toluene	24.4 µg					
	Xylene	18.4 µg					
Total:	Benzene	203 µg	2.0 E5 µg/Nm^3	62.3 ppm	900 µg	3.1 E5 µg/Nm^3	98.3 ppm
	Toluene	183 µg	1.8 E5 µg/Nm^3	47.5 ppm	413 µg	1.4 E5 µg/Nm^3	38.2 ppm
	Xylene	222 µg	2.2 E5 µg/Nm^3	50.2 ppm	291 µg	1.0 E5 µg/Nm^3	23.3 ppm
	BTX		6.0 E5 µg/Nm^3			5.5 E5 µg/Nm^3	
Average:	Benzene		2.6 E5 µg/Nm^3	81.4 ppm			
	Toluene		1.6 E5 µg/Nm^3	42.8 ppm			
	Xylene		1.6 E5 µg/Nm^3	36.8 ppm			
	BTX		5.8 E5 µg/Nm^3				

TABLE F-87. FUGITIVE EMISSIONS BTX GAS FRACTION ANALYSIS

			Charcoal Tube 0325-0530 12/14/79 6543 dry Ncc	
Front:	Benzene	1.6 µg		
	Toluene	.3 µg		
	Xylene	(9) µg		
Back:	Benzene	1.6 µg		
	Toluene			
	Xylene			
Total:	Benzene	3.2 µg	4.89 E2 µg/Nm³	0.15 ppm
	Toluene	.3 µg	4.59 E1 µg/Nm³	0.01 ppm
	Xylene	(9) µg	1.38 E3 µg/Nm³	0.32 ppm
	BTX		1.91 E3 µg/Nm³	

TABLE F-88. FUGITIVE EMISSIONS TOTAL ORGANICS ANALYSIS

RM-59	Tenax Tube Work Area 0930-0925 12/13-12/14 3.526 Nm³ (25°C, 1 atm)
FID/GC - Hydrocarbons	
Total Peak Area = 420 ug/Nm³ (0.13 ppm as benzene)	
HECD/GC - Sulfur	
Methyl thiophene	Present
Dimethyl or ethyl thiophene	0.5 ug/Nm³
Trimethyl thiophene	0.6 ug/Nm³
HECD/GC - Nitrogen	
Ethyl/methyl pyridine	Present
Trimethyl or ethyl methylpyridine	Present

F.2.5 Results of Analysis of RCRA Leachates for Pesticides and Herbicides

TABLE F-89. RCRA LEACHATES ANALYSES FOR PESTICIDES AND HERBICIDES

Sample	Endrin	Lindane	Methoxychlor	Toxaphene	2,4-D	Silvex
Cyclone Dust RCRA Leachate	ND	ND	ND	ND	ND	ND
Gasifier Ash RCRA Leachate	ND	ND	ND	ND	ND	ND
Leachate Blank	ND	ND	ND	ND	ND	ND

N.D. - not detected

The analysis of three samples for four pesticides and two herbicides was performed using electron capture gas chromatography. The column used was 1.8 meters x 2 mm I.D, glass packed with 5% OV-210 on Gas Chrom-Q (80/100 mesh) and was kept at 190°C for the organochlorine pesticides and at 170°C for the derivatized herbicides. Identification was by an external standard, freshly prepared.

Notes:

Herbicides	MDL*	RCRA Limit
2,4-D	0.8 ppb	10,000 ppb
Silvex	0.3 ppb	1,000 ppb
Pesticides		
Lindane	0.2 ppb	400 ppb
Endrin	2. ppb	20 ppb
Methoxychlor	2. ppb	10,000 ppb
Toxaphene	100 ppb	500 ppb

*Minimum Detectable Limit

APPENDIX G

LEVEL 1 EPA HEALTH EFFECTS TESTS ON COAL GASIFICATION SAMPLES

LEVEL 1 EPA HEALTH EFFECTS TESTS ON COAL GASIFICATION SAMPLES

Final Report
to
RADIAN CORPORATION
P. O. Box 9948
Austin, TX 78766

ADL Reference 84757
Subcontract under EPA Prime Contract 68-02-2147
(Task 18, Sub-Task 54)

August 26, 1980

Arthur D. Little, Inc.

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I. INTRODUCTION

Arthur D. Little, Inc., conducted Level 1 EPA Health Effects Tests on coal gasification process samples for the Radian Corporation. The samples were received on April 15, 1980.

The Test Matrix conducted is given below.

Test Matrix

		Bioassay			
Sample No.	Description	Ames	CHO	RAM	Rodent
4568	Dust	✓	✓	✓	
4658	Ash	✓	✓	✓	
4668	Ash Leachate	✓	✓		✓
4670	Dust Leachate	✓	✓		✓

II. SUMMARY OF RESULTS

Sample No.	Ames*	In Vitro Cytotoxicity ED$_{50}$** CHO	In Vitro Cytotoxicity ED$_{50}$** RAM	Rodent Test/Control***
4568	Negative	940	1000	-
4658	Negative	>1000	740†	-
4668	Negative	580	-	
4670	Negative	>600	-	

---

* For concentrations tested, see Section III.

** ED$_{50}$'s given in µl/ml or µg/ml.

*** Number of dead mice in test group over control group. Ten animals used in each group. See details of autopsy reports in Section V.

† For sample 4658 in the RAM assay, the ATP determinations indicated an ED$_{50}$ value of 740 µg/ml; all other parameters indicated an ED$_{50}$ value of >1000 µg/ml.

III. SALMONELLA MUTAGENESIS (AMES) ASSAY

Test Samples: 4568
4658
4668
4670

Summary

All samples were assayed in duplicate in the plate incorporation assay of Ames against Salmonella typhimurium strains TA-98, TA-100, TA-1535, TA-1537 and TA-1538 with and without metabolic activation. Solid samples were tested at four log doses, the highest dose being 1 mg/plate. Liquid samples were tested at 250, 200, 150 and 100 µl/plate.

No sample appeared to be mutagenic in the presence or absence of metabolic activation.

Materials and Methods

The above samples were tested in the plate incorporation mutagenesis assay of Ames. The Salmonella typhimurium strains TA-98, TA-100, TA-1535, TA-1537 and TA-1538 used in this study were obtained from Dr. Bruce N. Ames. The protocol for the assay is described in the IERL-RTP Procedures Manual, Level 1, EPA 600/6-77-04, April, 1977. The assay was conducted with and without metabolic activation (S-9) in a culture medium which contains insufficient histidine to allow the tester strains to proliferate sufficiently to give colonies. After incubation at 37°C for 48 hours, the mutant colonies (formed by his^+ revertants) are counted. Results are reported as total number of revertants per plate and the standard error of the mean is calculated.

Briefly, in this assay 0.5 ml of the test organism, 1.0 ml of the histidine/biotin supplement and 0.1 ml of the appropriate solid sample dilution (or 1.5 ml of the appropriate liquid dilution) were added to 10.0 ml of 0.6% molten top agar (or 9.0 ml of 0.6% molten top agar for liquid samples). Two ml of this molten top agar mixture was then pipetted onto each of duplicate Minimal Glucose Agar plates with and without 0.5 ml/plate of the S-9 mixture (Aroclor-induced rat S-9 prepared at Arthur D. Little, Inc., on July 15, 1980).

Controls which were included in the experiment consisted of negative (solvent) controls for the spontaneous reversion rate for each tester strain, and the positive controls listed below, compounds which do and do not require metabolic activation. Positive controls were made up fresh the day of the assay.

	Positive Control Chemicals
Tester Strain	Non-Activation (-S9)
TA-98	Daunomycin, 10 μg/plate
TA-100	Methylmethane sulfonate, 0.133 μl/plate
TA-1535	N-methyl-N'-nitro-N-nitrosoguanidine, 50 μg/plate
TA-1537	9-Aminoacridine, 50 μg/plate
TA-1538	2-Nitrofluorene, 10 μg/plate
	Activation (+S9)
All Strains	2-Anthramine, 10 μg/plate

Results

Results are presented in Table III-1.

No mutagenic activity was evident in any sample.

All sterility controls (inoculated on Nutrient Agar plates) were negative: solvent, sample, S-9 mix and histidine/biotin supplement. Uninoculated media controls, which were also negative included Minimal Glucose Agar, Nutrient Agar, and Nutrient Broth.

Senior Technician Evaluating Material
Elizabeth M. Prescott
Elizabeth M. Prescott, B.S.

Case Leader, Senior Staff
Mildred G. Broome
Mildred G. Broome, Ph.D.

Section Leader, Bio/Medical
Sciences Section
Andrew Sivak
Andrew Sivak, Ph.D.

TABLE III-1

AMES ASSAY I

RADIAN SAMPLES RECEIVED APRIL 15, 1980

#4568 - DUST; #4658 - ASH; #4668 - ASH LEACHATE; #4670 - DUST LEACHATE

	Revertants Per Plate*									
	TA-98		TA-1537		TA-1538		TA-100		TA-1535	
	-S9	+S9	-S9	+S9	-S9	+S9	-S9	+S9	-S9	+S9
Control (DMSO)	20 ± 2	21 ± 3	8 ± 0	10 ± 1	9 ± 1	13 ± 2	90 ± 6	91 ± 7	12 ± 2	12 ± 2
2-Anthramine** 10 μg/plate	32 ± 3	>500	10 ± 1	265 ± 12	14 ± 2	>500	115 ± 5	>500	12 ± 1	72 ± 2
Daunomycin*** 10 μg/plate	>500	>500								
9-Aminoacridine† 50 μg/plate			159 ± 3	81 ± 2						
2-Nitrofluorene** 10 μg/plate					>500	>500				
Methylmethane sulfonate** 0.133 ul/plate							361 ± 3	430 ± 26		
N-Methyl-N'-nitro-N-nitrosoguanidine** 50 μg/plate									TNTC††	TNTC
#4568 - Dust**										
0.001 mg/plate	15 ± 2	15 ± 0	9 ± 0	8 ± 1	11 ± 1	8 ± 0	92 ± 6	87 ± 2	8 ± 1	11 ± 2
0.01 mg/plate	20 ± 6	19 ± 2	9 ± 1	7 ± 1	6 ± 0	14 ± 1	99 ± 11	93 ± 4	12 ± 3	11 ± 2
0.1 mg/plate	23 ± 5	22 ± 3	8 ± 1	8 ± 1	9 ± 2	10 ± 2	87 ± 3	91 ± 1	15 ± 3	9 ± 1
1.0 mg/plate	17 ± 3	17 ± 5	6 ± 1	7 ± 2	12 ± 0	12 ± 2	97 ± 7	103 ± 10	14 ± 0	10 ± 1
#4658 - Ash**										
0.001 mg/plate	16 ± 2	15 ± 1	7 ± 1	7 ± 1	10 ± 0	10 ± 1	103 ± 9	97 ± 2	11 ± 3	8 ± 0
0.01 mg/plate	17 ± 1	14 ± 1	9 ± 1	5 ± 1	8 ± 1	12 ± 3	82 ± 2	101 ± 7	12 ± 2	10 ± 1
0.1 mg/plate	16 ± 1	13 ± 2	8 ± 1	8 ± 1	8 ± 2	15 ± 1	92 ± 4	100 ± 3	15 ± 1	9 ± 0
1.0 mg/plate	16 ± 2	18 ± 2	8 ± 0	7 ± 1	9 ± 0	13 ± 1	92 ± 7	86 ± 15	12 ± 1	10 ± 1
#4668 - Ash Leachate***										
100 μl/plate	17 ± 1	20 ± 1	7 ± 1	6 ± 1	10 ± 0	17 ± 1	102 ± 9	98 ± 3	13 ± 2	7 ± 0
150 μl/plate	20 ± 1	26 ± 3	6 ± 1	7 ± 1	7 ± 0	12 ± 1	97 ± 2	107 ± 1	11 ± 1	6 ± 0
200 μl/plate	21 ± 1	19 ± 1	6 ± 1	7 ± 1	6 ± 1	12 ± 2	92 ± 4	92 ± 1	10 ± 1	7 ± 1
250 μl/plate	19 ± 4	20 ± 0	7 ± 0	8 ± 2	8 ± 1	13 ± 2	88 ± 2	103 ± 2	13 ± 3	8 ± 2
#4670 - Dust Leachate***										
100 μl/plate	18 ± 2	17 ± 3	7 ± 1	7 ± 0	9 ± 1	15 ± 3	96 ± 5	103 ± 3	8 ± 0	7 ± 0
150 μl/plate	22 ± 2	20 ± 1	8 ± 1	6 ± 1	15 ± 2	13 ± 1	99 ± 7	103 ± 12	10 ± 0	8 ± 2
200 μl/plate	21 ± 1	16 ± 2	8 ± 1	7 ± 0	9 ± 1	21 ± 1	81 ± 2	108 ± 1	11 ± 1	10 ± 1
250 μl/plate	21 ± 4	20 ± 4	9 ± 1	6 ± 1	11 ± 3	16 ± 0	104 ± 5	90 ± 15	14 ± 1	12 ± 2

---

* Mean of 2 replicate plates ± standard error of the mean.

** Dissolved in dimethylsulfoxide (DMSO).

*** Dissolved in sterile distilled water.

† Dissolved in 95% ethanol.

†† Too numerous to count.

IV. IN VITRO CYTOTOXICITY ASSAYS

A summary of results for all cytotoxicity assays is given in Table IV-1.

A. RABBIT ALVEOLAR MACROPHAGE (RAM) ASSAY

Test Samples: 4568
4658

Summary

Samples 4568 and 4658 were tested in triplicate in the RAM assay at 1000, 300, 100, 30 and 10 µg/ml. Determinations of total cell counts, cell viability (trypan blue exclusion), viability index, protein and ATP levels made at 20 hours showed ED_{50} values for each of these parameters to be >1000 µg/ml for sample 4568. For sample 4658, ED_{50} values for total cell counts, cell viability (trypan blue exclusion), viability index and protein were >1000 µg/ml; ATP levels at 20 hours showed an ED_{50} value of 740 µg/ml.

Materials

Samples 4568 (Dust) and 4658 (Ash) were tested for bacterial contamination by inoculation into Trypticase Soy Broth, Thioglycollate Broth and Sabouraud Liquid Broth and incubated at 25°C and 37°C. No evidence of contamination was observed after 7 days with sample 4658. Evidence of bacterial contamination was observed after 4 days' incubation of sample 4568 at 37°C. One mg/ml of sample 4568 was then incubated in the medium used in the RAM assay (Medium 199 containing appropriate antibiotics) and showed no evidence of contamination after 7 days.

TABLE IV-1

SUMMARY OF RESULTS OF IN VITRO TESTS

Sample	Description	Test System	Toxicity (ED_{50})
4568	Dust	RAM	No detectable toxicity (>1000 μg/ml)
		CHO	Low toxicity (970 μg/ml)
4658	Ash	RAM	Low toxicity (740 μg/ml)
		CHO	No detectable toxicity (>1000 μg/ml)
4668	Ash Leachate	CHO	Low toxicity (580 μl/ml)
4670	Dust Leachate	CHO	No detectable toxicity (>600 μl/ml)

Methods

Two New Zealand albino female rabbits, purchased from Pine Acres Rabbitry, West Brattleboro, Rhode Island, were received on June 5, 1980, and two on June 19, 1980, and housed individually in Rooms 138 and B14D of 38 Memorial Drive, Cambridge, Massachusetts, until June 10, 1980, and June 24, 1980, respectively.

On June 10, 1980, and June 24, 1980, two animals each were sacrificed following the protocol of Coffin _et_ _al_. (Arch. Environ. Health, 1968, _16_: 633-636) with 150 mg Nembutal injected into the marginal ear vein. Tracheostomies were performed, and the macrophages were collected using 5 instillation volumes of 30 ml of prewarmed (37°C) sterile 0.9% physiological saline.

The method for the RAM assay is described in the IERL-RTP Procedures Manual, Level 1, EPA 600/6-77-04, April, 1977. Macrophages were centrifuged in 50 ml sterile tubes for seven minutes at 800 rpm and 9°C, and resuspended in fresh physiological saline. Slides were made and the viability of cells was determined. The cells were re-centrifuged and suspended in an appropriate volume of Medium 199. Two ml of cells (2.0×10^6 cells) were added to each 25 cm^2 flask. Two ml of the appropriate dilution of sample 4568, 4658 or of the vehicle control were then added. The flasks were placed on a rocker platform in a 37°C humidified 5% CO_2 atmosphere and incubated for 20 hours. At the end of the 20-hour incubation period, cell viability, total protein and ATP content were determined.

Results

Sample 4568 gave ED_{50} values of >1000 μg/ml for cell viability (trypan blue exclusion), viability index, protein and ATP levels at 20 hours. Detailed results are shown in Table IV-2 and Figure IV-1.

TABLE IV-2

RESULTS OF RAM ASSAY OF RADIAN SAMPLE 4568

Concentration	% Viable	Viability Index	Total Protein		ATP	
			µg/ml	% T/C	fg/10^6 Cells	% T/C
1000 µg/ml	57.2	67.7	257.3	110.7	4.71×10^8	108.5
	48.4	43.6	266.8	114.8	4.03×10^8	92.9
	56.6	59.1	246.9	106.2	6.88×10^8	158.5
$\bar{x}$	54.1	56.8	257.0	110.5	5.20×10^8	120.0
300 µg/ml	73.7	96.4	243.6	104.8	4.17×10^8	96.1
	74.2	80.2	231.8	99.7	5.95×10^8	137.1
	69.3	82.7	244.0	104.9	3.92×10^8	90.3
$\bar{x}$	72.4	86.4	239.8	103.1	4.68×10^8	107.9
100 µg/ml	73.6	84.6	272.6	117.2	5.81×10^8	133.9
	67.2	63.9	223.2	96.0	6.37×10^8	146.8
	73.6	69.5	229.2	98.6	4.40×10^8	101.4
$\bar{x}$	71.5	72.7	241.6	103.9	5.53×10^8	127.4
30 µg/ml	77.3	70.6	261.7	112.6	5.40×10^8	124.4
	74.0	78.1	237.8	102.3	6.80×10^8	156.7
	72.9	61.5	219.1	94.2	6.13×10^8	141.2
$\bar{x}$	74.7	70.1	239.5	103.0	6.29×10^8	145.0
10 µg/ml	78.9	59.0	232.7	100.1	9.55×10^8	220.0
	76.8	56.5	210.4	90.5	6.74×10^8	155.3
	73.5	66.9	226.9	97.6	3.27×10^8	75.3
$\bar{x}$	76.4	60.8	223.3	96.0	6.52×10^8	150.3
Controls	81.2		224.2		5.95×10^8	
	82.2		231.6		3.91×10^8	
	82.5		232.2		6.08×10^8	
	82.6		237.2		4.10×10^8	
	82.5		237.2		4.24×10^8	
	85.1		241.5		4.35×10^8	
	82.7		228.7		2.64×10^8	
	83.9		238.2		4.63×10^8	
	84.1		235.7		4.01×10^8	
	80.8		218.7		3.47×10^8	
$\bar{x}$	82.8		232.5		4.34×10^8	

TABLE IV-2

RESULTS OF RAM ASSAY OF RADIAN SAMPLE 4568

(continued)

Footnote

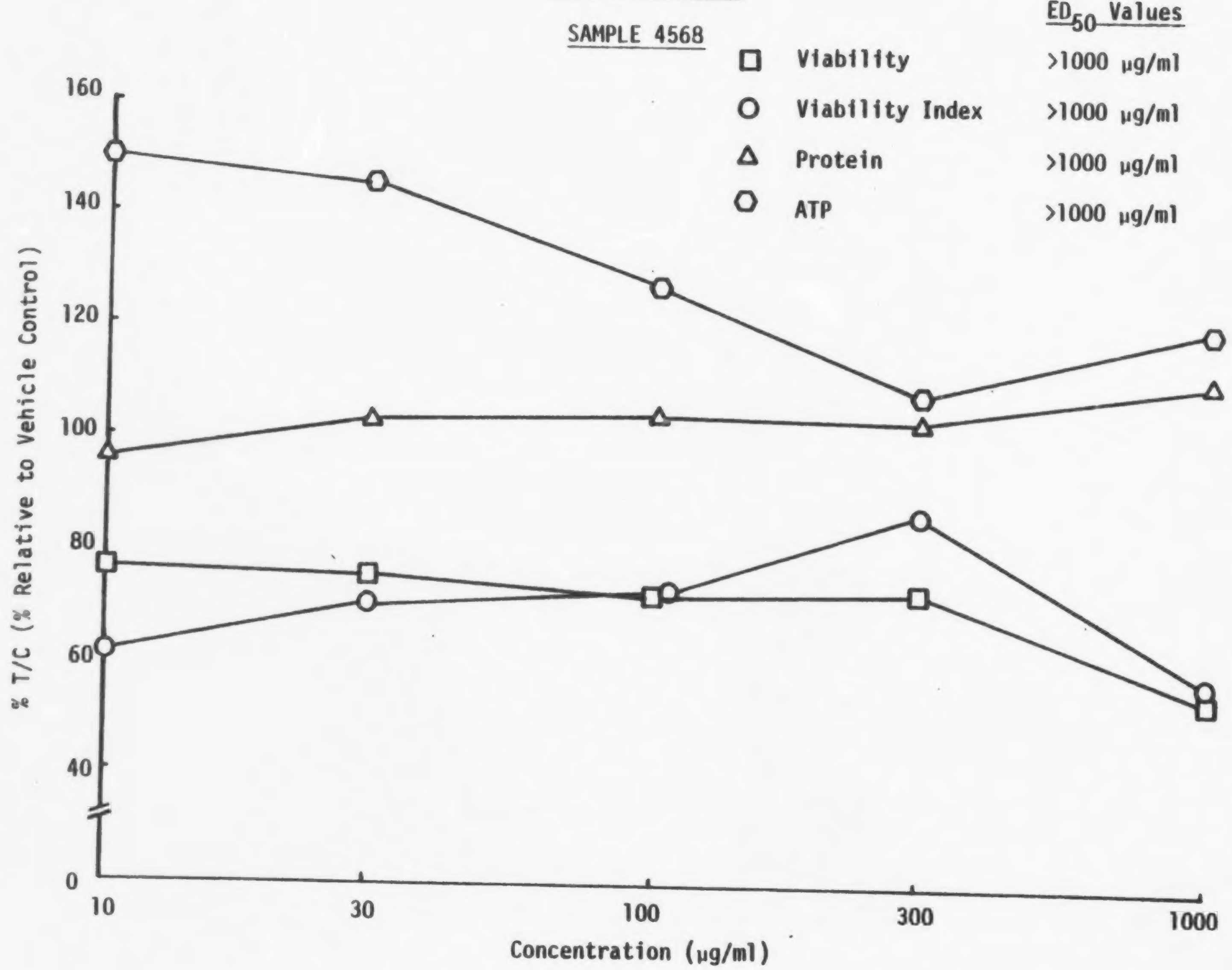
Quality Control Data and Results of RAM Assay of Sample 4568:

No. of Rabbits Used	2
Viability of Macrophages	99.1%
Total Cell Number Recovered	7.2×10^7
Dilution Volume	72 ml
Cells/ml	1.0×10^6
% Macrophages	96.7
Incubation Time	20 hours
pH of Samples (T_0)	7.0
pH of Samples (T_{20})	6.9 - 1000 and 300 μg/ml 7.0 - 100, 30 and 10 μg/ml
Vehicle Used	Medium 199
Sterility of Macrophages	No growth in thioglycollate broth, trypticase soy broth or Sabouraud liquid at room temperature or 37°C after 7 days
ED_{50} Values	
Cell Count	>1000 μg/ml
Viability	>1000 μg/ml
Viability Index	>1000 μg/ml
Protein	>1000 μg/ml
ATP	>1000 μg/ml

FIGURE IV-1

RADIAN RAM ASSAY

SAMPLE 4568



Sample 4658 gave ED_{50} values of >1000 µg/ml for cell viability (trypan blue exclusion), viability index and protein. An ED_{50} value of 740 µg/ml was obtained using ATP level determinations. Detailed results are shown in Table IV-3 and Figure IV-2.

B. CHINESE HAMSTER OVARY (CHO) CLONAL TOXICITY ASSAY

Test Samples: 4568
4658
4668
4670

Summary

The above samples were assayed in triplicate in the CHO assay at concentrations of 1000, 300, 100, 30 and 10 µg/ml for solid samples 4568 and 4658 and at concentrations of 600, 200, 60, 20 and 6 µl/ml for liquid samples 4668 and 4670.

For solid samples 4568 and 4658, ED_{50} values of 970 µg/ml and >1000 µg/ml, respectively, were found; for both liquid samples 4668 and 4670, ED_{50} values of 580 µl/ml and >600 µl/ml, respectively, were found.

Materials and Methods

Sterility tests for samples 4568 and 4658 have been previously described. Samples 4668 and 4670 were tested for bacterial contamination by inoculation into Trypticase Soy Broth, Thioglycollate Broth, and Saubouraud Liquid Broth and incubated at 25°C and 37°C. No evidence of contamination was found after 7 days of incubation.

TABLE IV-3

RESULTS OF RAM ASSAY OF RADIAN SAMPLE 4658

Concentration	% Viable	Viability Index	Total Protein		ATP	
			µg/ml	% T/C	fg/10^6 Cells	% T/C
1000 µg/ml	69.8	65.3	114.3	98.3	1.09×10^9	51.4
	66.0	52.5	129.8	111.6	9.85×10^8	46.5
	69.8	74.0	100.4	86.3	9.09×10^8	42.9
$\bar{x}$	68.5	63.7	114.8	98.7	9.95×10^8	46.9
300 µg/ml	79.4	86.1	119.9	103.1	1.23×10^9	58.0
	78.8	79.2	106.8	91.8	1.19×10^9	56.1
	81.3	91.5	115.8	99.6	1.42×10^9	67.0
$\bar{x}$	79.8	85.4	114.2	98.2	1.28×10^9	60.4
100 µg/ml	76.7	86.7	107.5	92.4	1.39×10^9	65.6
	76.8	79.9	108.3	93.1	1.89×10^9	89.2
	83.7	113.0	127.9	110.0	1.10×10^9	51.9
$\bar{x}$	79.1	92.9	114.6	98.5	1.46×10^9	68.9
30 µg/ml	79.2	81.2	102.2	87.9	1.43×10^9	67.5
	84.0	87.8	121.3	104.3	1.76×10^9	83.0
	82.0	96.5	144.9	124.6	1.22×10^9	57.5
$\bar{x}$	81.8	88.3	122.8	105.6	1.47×10^9	69.3
10 µg/ml	85.9	91.5	114.7	98.6	1.30×10^9	61.3
	85.8	88.4	117.5	101.0	1.78×10^9	84.0
	85.7	90.0	100.2	86.2	1.82×10^9	85.8
$\bar{x}$	85.8	90.1	110.8	95.3	1.63×10^9	77.0
Controls	88.5		102.9		1.89×10^9	
	87.6		122.2		1.50×10^9	
	93.8		111.8		1.85×10^9	
	84.7		111.0		1.90×10^9	
	85.0		105.5		2.43×10^9	
	86.8		99.3		2.16×10^9	
	89.5		113.6		2.14×10^9	
	83.1		151.1		1.88×10^9	
	83.0		128.9		3.31×10^9	
$\bar{x}$	86.9		116.3		2.12×10^9	

TABLE IV-3

RESULTS OF RAM ASSAY OF RADIAN SAMPLE 4658

(continued)

Footnote

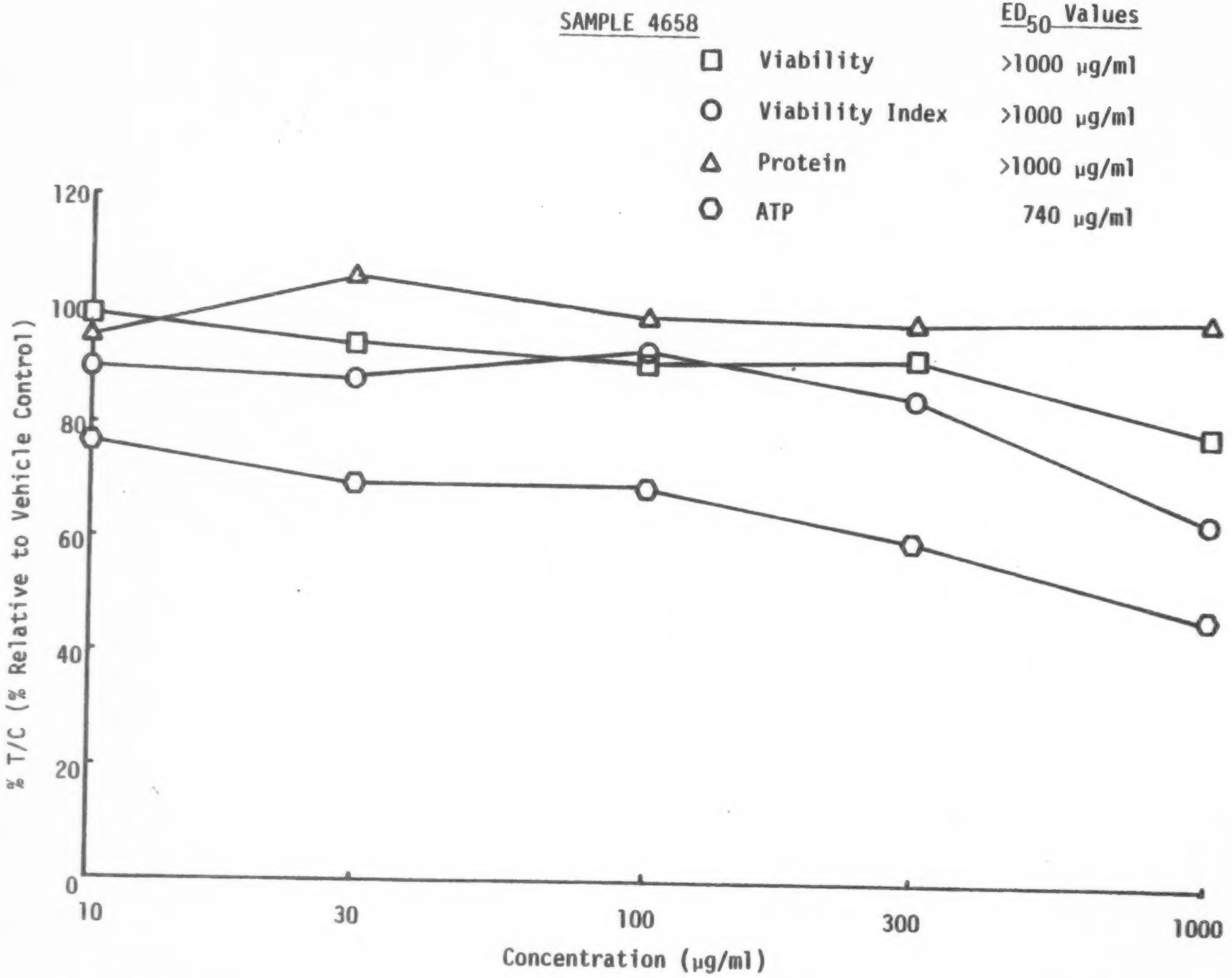
Quality Control Data and Results of RAM Assay of Sample 4658:

No. of Rabbits Used	2
Viability of Macrophages	94.0%
Total Cell Number Recovered	5.0×10^7
Dilution Volume	50 ml
Cells/ml	1.0×10^6
% Macrophages	97.3
Incubation Time	20 hours
pH of Samples (T_o)	6.6 - 1000 μg/ml 6.8 - 300 μg/ml 7.0 - 100, 30 and 10 μg/ml
pH of Samples (T_{20})	7.0
Vehicle Used	Medium 199
Sterility of Macrophages	One tube at 37°C showed contamination at 7 days
ED_{50} Values	
Cell count	>1000 μg/ml
Viability	>1000 μg/ml
Viability Index	>1000 μg/ml
Protein	>1000 μg/ml
ATP	740 μg/ml

FIGURE IV-2

RADIAN RAM ASSAY

SAMPLE 4658



Chinese hamster ovary fibroblasts were removed from the liquid nitrogen frozen tumor bank on April 15, 1980, and maintained as monolayer cultures in Dulbecco's modified Eagle's Minimum Essential Medium supplemented with 10% fetal calf serum, 100 U/ml penicillin and 100 µg/ml streptomycin until May 12, 1980. At that time, the medium was changed to complete Ham's F-12 which was used for all subsequent cell passages and testing.

Liquid samples 4668 and 4670 were assayed in an experiment on May 28, 1980 (Experiment 1). CHO cells in logarithmic growth phase from passage 9 were suspended at 50 cells/ml and 4 ml of this cell suspension were dispensed into each of 60 mm tissue culture dishes. Cells were allowed to adhere for six hours in a humidified 5% CO_2 atmosphere at 37°C. The medium was aspirated and 4 ml of the samples appropriately diluted in 2.5X complete Ham's F-10 medium were added. Cultures treated with sodium azide (NaN_3, 600 and 100 µg/ml) and untreated cultures were also used. The dishes were returned to the incubator for an additional 24 hours after which time all dishes were washed three times with phosphate buffered saline and refed with 5 ml of complete Ham's F-12 medium. All dishes were returned to the incubator for an additional six days to allow clones to develop. At the end of the final incubation period, all dishes were drained, washed once with phosphate buffered saline, fixed for at least 15 minutes with 100% methanol and stained 10-15 minutes with 10% Giemsa. Colony counts were determined on an Artec Colony Counter and manually.

Solid samples 4568 and 4658 were also assayed in an experiment on May 28, 1980 (Experiment 2). CHO cells from passage 9 were suspended at 50 cells/ml in Ham's F-12 and 60 mm dishes were inoculated with 4 ml of the cell suspension. The cells were allowed to adhere for six hours in a humidified 5% CO_2 atmosphere at 37°C. The medium was then aspirated and 4 ml of the appropriately diluted sample in complete Ham's F-12 was added. Untreated dish cultures were included as media controls. Positive controls were treated with sodium azide at 600 and 100 µg/ml. All cultures were drained after 24 hours and washed three times with phosphate buffered saline. Cultures were refed with 5 ml complete Ham's F-12. The media from all cultures were drained after six additional days of incubation. The colonies were fixed with 100% methanol and stained with 10% Giemsa. The plates were counted on the Artec Colony Counter and manually.

Results

Detailed results for samples 4568, 4658, 4668 and 4670 are shown in Tables IV-4 and IV-5, and Figures IV-3 and IV-4. The response of the negative controls is within acceptable limits in both experiments. The cytotoxicity of the positive control (NaN_3) in these experiments, although variable, is being used in the establishment of a historical data base, and therefore, quality control limits have not as yet been established.

The ED_{50}'s and the EPA toxicity classification are given below for these four samples:

Sample	ED_{50}	Toxicity
4568	970 μg/ml	Low toxicity
4658	>1000 μg/ml	No detectable toxicity
4668	580 μl/ml	Low toxicity
4670	>600 μl/ml	No detectable toxicity

Senior Technician Evaluating Material

Carolyn M. Creswell
Carolyn M. Creswell, M.A.

Case Leader and Unit Manager,
Cell Biology/Microbiology

Mildred G. Broome
Mildred G. Broome, Ph.D.

Vice President, Section Manager
Bio/Medical Sciences Section

Andrew Sivak
Andrew Sivak, Ph.D.

TABLE IV-4

CHO CLONAL TOXICITY ASSAY RESULTS - EXPERIMENT NO. 1

Sample	Concentration	pH	No. of Colonies	Surviving Fraction
Untreated Control	-	7.0	185	1.00
			176	1.00
			212	1.00
			194	1.00
			214	1.00
			207	1.00
			176	1.00
			182	1.00
			202	1.00
			183	1.00
Mean ± Standard Deviation			193.1 ± 14.7*	1.00
Positive Control (NaN_3)	600 µg/ml	7.0	61	0.32
			51	0.26
			53	0.27
			64	0.33
			57	0.30
Mean ± Standard Deviation			57.2 ± 5.4*	0.30 ± 0.04**
NaN_3	100 µg/ml	7.0	108	0.56
			86	0.45
			65	0.34
			124	0.64
			108	0.56
Mean ± Standard Deviation			98.2 ± 23.0*	0.51 ± 0.10**

TABLE IV-4

CHO CLONAL TOXICITY ASSAY RESULTS - EXPERIMENT NO. 1

(continued)

Sample	pH	Colony Counts (µl/ml)				
		600	200	60	20	6
4668	7.0	79	189	160	205[a]	262[a]
		114	164	164	220	234
		89	118	136	204	212
Mean		94.0	157.0	153.3	209.7	236.0
Standard Deviation*		18.0	36.0	15.1	9.0	25.1
Surviving Fraction		0.49	0.81	0.79	1.09	1.22
Standard Deviation**		0.10	0.20	0.10	0.09	0.16
4670	7.0	160	137	180	175	169
		166	118	141	203	175
		148	158	143	216	117
Mean		158.0	137.7	154.7	198.0	153.7
Standard Deviation*		9.2	20.0	22.0	21.0	31.9
Surviving Fraction		0.82	0.71	0.80	1.03	0.80
Standard Deviation**		0.08	0.12	0.13	0.13	0.18

* Standard Deviation $= \sqrt{\left(\frac{\Sigma X^2}{N} - \frac{\Sigma X^2}{N^2}\right) \times \frac{N}{N-1}}$

** Standard Deviation $\simeq \sqrt{\frac{\text{Var } T + \left(\frac{T}{C}\right)^2 \text{VarC}}{C^2}}$

[a] Dishes from sample 4668 at 20 µl/ml and 6 µl/ml contained numerous small colonies which gave unusually high readings.

FIGURE IV-3

RADIAN CHO CLONAL TOXICITY ASSAY

EXPERIMENT NO. 1

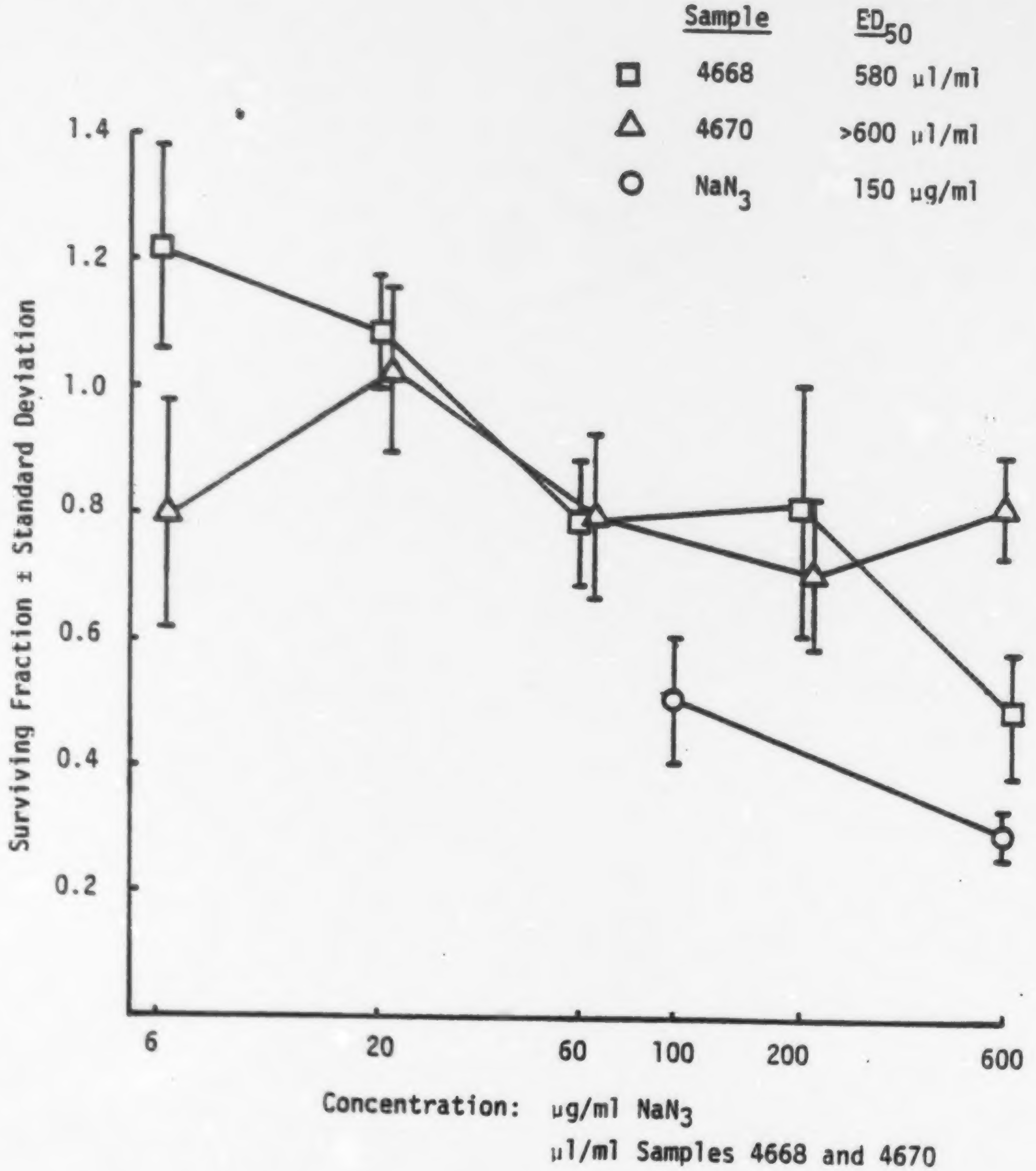


TABLE IV-5

CHO CLONAL TOXICITY ASSAY RESULTS - EXPERIMENT NO. 2

Sample	Concentration	pH	No. of Colonies	Surviving Fraction
Untreated Control	-	7.0	177	1.00
			143	1.00
			199	1.00
			114	1.00
			135	1.00
			191	1.00
			190	1.00
			110	1.00
			67	1.00
			152	1.00
Mean ± Standard Deviation			147.8 ± 42.7*	1.00
Positive Control (NaN_3)	600 μg/ml	7.0	42	0.28
			43	0.29
			42	0.28
Mean ± Standard Deviation			42.3 ± 0.6*	0.29 ± 0.08**
NaN_3	100 μg/ml	7.0	41	0.28
			146	0.99
			146	0.99
			56	0.38
			96	0.65
Mean ± Standard Deviation			97.0 ± 49.0*	0.66 ± 0.38**

TABLE IV-5

CHO CLONAL TOXICITY ASSAY RESULTS - EXPERIMENT NO. 2

(continued)

Sample	pH	Colony Counts (μg/ml)				
		1000	300	100	30	10
4568	7.0	59	133	126	181	170
		85	114	165	123	202
		74	114	131	122	190
Mean		72.7	120.3	140.7	142.0	187.3
Standard Deviation*		13.1	11.0	21.2	33.8	16.2
Surviving Fraction		0.49	0.81	0.95	0.96	1.27
Standard Deviation**		0.17	0.25	0.31	0.36	0.38
4658	7.0	102	148	164	141	145
		98	128	127	146	176
		90	166	180	144	161
Mean		96.7	147.3	157.0	143.7	160.7
Standard Deviation*		6.1	19.0	27.2	2.5	15.5
Surviving Fraction		0.65	1.00	1.06	0.97	1.09
Standard Deviation**		0.19	0.32	0.36	0.28	0.33

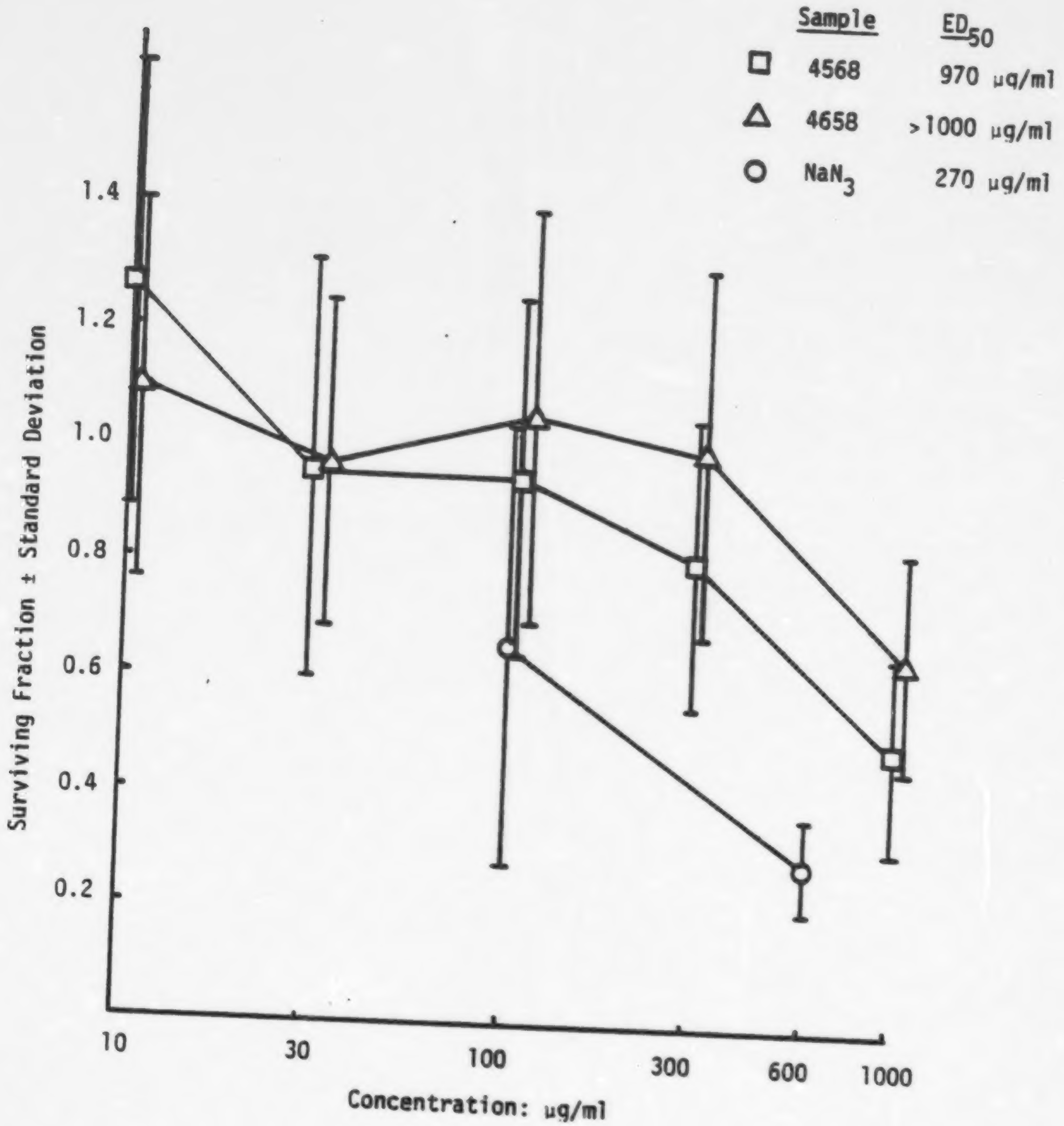
* Standard Deviation = $\sqrt{\frac{\Sigma X^2}{N} - \frac{\Sigma X^2}{N^2} \times \frac{N}{N-T}}$

** Standard Deviation $\simeq \sqrt{\frac{\text{Var } T + \left(\frac{T}{C}\right)^2 \text{VarC}}{C^2}}$

FIGURE IV-4

RADIAN CHO CLONAL TOXICITY ASSAY

EXPERIMENT NO. 2



V. ACUTE IN VIVO TOXICOLOGICAL TESTS IN RODENTS

Test Samples

4668

4670

Summary

Each sample was administered by gavage as a single dose of 10 ml/kg to male and female CDF_1 mice (5♂, 5♀). Animals were observed daily for signs of general health. Animals were killed and autopsied on the 15th day following dosing. Gross autopsy revealed white coronary blood vessel color in a number of treated animals. The relationship between this effect and the treatment is unknown. No animals died during the observation period.

Materials

The materials were received by Dr. Mildred G. Broome at Arthur D. Little, Inc., and were identified as follows:

Number	Description
4668	Ash Leachate
4670	Dust Leachate

Methods

A group of male and female CDF_1 mice was obtained from Charles River Breeding Laboratories and placed in quarantine for one week in Room B-13-E, 38 Memorial Drive, Cambridge, Massachusetts, Arthur D. Little, Inc. From this group 5 males and 5 females of comparable body weights were selected for testing of each compound. All selected animals appeared to be healthy.

Test material was administered by gavage in a single dose to each animal. The dose employed in each case was 10 ml/kg. Both samples were used as received. Control animals were treated with 10 ml/kg tap water by gavage.

Body weights were recorded on day of dosing (Day 1), Day 8 and Day 15. Animals were observed daily for signs of general health. A gross autopsy was performed on each animal at sacrifice. Organ weights were not obtained.

TABLE V-1

Summary of Results of Acute Oral Toxicity Tests in Mice

Compound	Mortality (Day 15)	% Weight Gain (Day 15)	White Coronary BV *	Local Cardiac Ischemia *
4668	0/10	4%	3/10	1/10
4670	0/10	4%	4/10	1/10
Tap Water-Control	0/10	4%	0/10	0/10

---

*Observed at autopsy.

TABLE V-2

Summary of Single-Dose Oral Toxicity of 4668

Species:		Mouse
Strain:		CDF$_1$
Body Weight Range (gm):		
Day 1	19-26	
Day 8	18.9-26.6	
Day 15	20-27.9	
Formulation:		Used as Received
Concentration:		Unknown
Approximate Volume Administered:		0.22 ml

Dosage (ml/kg), Mortality, and Percent Mean Body Weight Gain of Survivors Post-Treatment

Dosage	Mortality		% Mean Body Weight Gain	
	Day 8	Day 15	Day 8	Day 15
Control, Tap Water - 10 ml/kg	0/10	0/10	4%	4%
4668 10 ml/kg	0/10	0/10	0%	4%

Numbers rounded to nearest integer.

TABLE V-3

Summary of Single-Dose Oral Toxicity of 4670

Species:		Mouse
Strain:		CDF_1
Body Weight Range (gm):		
Day 1	19-25.6	
Day 8	18.9-26.6	
Day 15	20-28.2	
Formulation:		Used as Received
Concentration:		Unknown
Approximate Volume Administered:		0.22 ml

Dosage (ml/kg), Mortality, and Percent Mean Body Weight Gain of Survivors Post-Treatment

Dosage	Mortality		% Mean Body Weight Gain	
	Day 8	Day 15	Day 8	Day 15
Control, Tap Water 10 ml/kg	0/10	0/10	4%	4%
4670 10 ml/kg	0/10	0/10	0%	4%

Numbers rounded to nearest integer.

Results

Results are summarized in Table 1 and individually presented in Tables 2 and 3. There was no mortality. At autopsy, several animals in each experimental group were observed to have white coronary blood vessels. Areas of cardiac muscle ischemia were also observed in some of the same animals. The significance of these observations is unknown. Mean body weights at Day 15 were 4% higher than mean initial weight for each group.

Conclusions

Testing of acute oral toxicity in mice has demonstrated samples 4668 and 4670 to have no lethal effects at a dose of 10 ml/kg.

Senior Technician Evaluating Material

Peter C. Rachwall

Peter C. Rachwall

Subcase Leader and Unit Manager,
Toxicology

Rosalind C. Anderson

Rosalind C. Anderson, Ph.D.

Case Leader

Mildred G. Broome

Mildred G. Broome, Ph.D.

Vice-President, Section Manager
Bio/Medical Sciences Section

Andrew Sivak

Andrew Sivak, Ph.D.

APPENDIX H

TOXICITY OF TWO COAL GASIFICATION SOLID EFFLUENT LEACHATE SAMPLES TO THE FRESHWATER ALGA SELANASTRUM CAPRICORNUTUM

Radian Corporation
8500 Shoal Creek Boulevard
Post Office Box 9948
Austin, Texas 78766

Project Officer:
Michael R. Fuchs

Project Number L39
Report Number BP-80-4-69

EG&G, Bionomics
Marine Research Laboratory
Route 6, Box 1002
Pensacola, Florida 32507
April 1980

Phytotoxicity tests were conducted at EG&G, Bionomics Marine Research Laboratory (BMRL), Pensacola, Florida, to determine the effect of two coal gasification solid effluent leachate samples on the freshwater alga *Selenastrum capricornutum*. Results of each test are reported as 14-day EC50's (the concentrations of each effluent estimated to cause a 50% decrease of biomass, measured as dry cell weight, in exposed cultures as compared to the control after 14 days of exposure).

All data related to this study are stored at BMRL.

MATERIALS AND METHODS

Test material

The samples, received on 11 March 1980, were contained in 1-liter (ℓ) plastic bottles labeled "4568 neutral" and "4658, neutral bioassay." The effluents were clear liquids. The samples were stored at 4±1 degrees Celsius (°C) from the time of receipt until testing was initiated. Concentrations are reported here as the percentage (%) of leachate in algal growth medium based on volume:volume measurements.

Test alga

The freshwater alga tested was the unicellular green alga *Selenastrum capricornutum*. The culture was obtained from the U.S. Environmental Protection Agency's Environmental Research Laboratory, Corvallis, Oregon, and maintained in stock culture at BMRL.

Test conditions

Culture and test procedures followed those of U.S. Environmental Protection Agency (1977). Cultures were incubated at 24±1°C under approximately 4,000 lux illumination. Test containers were 125-milliliter (mℓ) flasks, each of which contained 50 mℓ of test medium. Test concentrations were prepared by diluting the leachates with algal growth medium. The leachates were filtered through 0.45-micrometer (μm) pore size membrane filters before testing.

Measurements of in vivo chlorophyll a in cultures were performed by using a Turner Model 111 fluorometer. Gravimetric methods for measurement of dry cell weights followed those outlined by U.S. Environmental Protection Agency (1977), Section 3.4.1.3; Method II. Filters used were Millipore® type BD, 0.6-μm pore size.

Growth constants (k) were calculated by using measurements of in vivo chlorophyll a after 5 days of exposure and the following equation:

$$k = \frac{\log_2 (x_2/x_1)}{t_2-t_1}$$

where

k = the number of divisions per day
x_2 = in vivo chlorophyll a at day 5
x_1 = in vivo chlorophyll a at day 1
t_2-t_1 = elapsed time (days between in vivo chlorophyll a measurements).

The tests were conducted 17-31 March 1980.

Statistical analyses

A graphically interpolated (APHA et al., 1976) 14-day EC50, based on decrease of dry cell weights, was determined for each leachate.

RESULTS AND DISCUSSION

Leachate 4568

After 14 days of exposure, decrease of in vivo chlorophyll a was from 48% in cultures exposed to 1% leachate to 96% in those exposed to 6% leachate; cultures exposed to test concentrations $\leq$0.6% leachate exhibited an increase of in vivo chlorophyll a. Decrease of dry cell weight after 14 days of exposure was from 0% in cultures exposed to 0.1% leachate to 96% in cultures exposed to 6% leachate (Table 1).

The graphically interpolated 14-day EC50, based on decrease of dry cell weight, was 3% leachate (Figure 1).

After 5 days of exposure, growth constants of cultures exposed to test concentrations $\geq$0.6% leachate were significantly less than the control. The k values, based on in vivo chlorophyll a, were from 0.35 for cultures exposed to 6% leachate to 1.68 for the control culture (Table 2).

Leachate 4658

After 14 days of exposure, decrease of in vivo chlorophyll a was from 6% in cultures exposed to 0.6% leachate to 92% in cultures exposed to 6% leachate; in vivo chlorophyll a increased 8% in cultures exposed to 1% leachate. Decrease of dry cell weight after 14 days was from 0% in cultures exposed to 0.3% and 0.6% leachate to 86% in those exposed to 6% leachate (Table 3).

The graphically interpolated 14-day EC50, based on dry cell weight, was 4% leachate (Figure 2).

After 5 days of exposure, growth constants of cultures exposed to test concentrations $\geq$0.6% leachate were significantly less than the control. The k values, based on in vivo chlorophyll a, were from 0.30 for cultures exposed to 6% leachate to 1.68 for the control cultures (Table 4).

It should be noted that the toxicity of the leachates dictated that much lower concentrations be tested than the concentrations recommended by EPA (1977). Exposure of algal cultures to recommended concentrations caused significant effect after only four days (see BMRL report number BP-80-3-56) and necessitated the tests reported here at lower concentrations.

REFERENCES

APHA, AWWA, and WPCF. 1976. Standard methods for the examination of water and wastewater (Fourteenth edition.) American Public Health Assoc., Washington, D.C. 1,193 pp.

U.S. Environmental Protection Agency. 1977. IERL-RTP procedures manual: Level 1 environmental assessment biological tests for pilot studies. EPA-600/8-77-043. pp. 40-50.

TABLE 1. Results of a 14-day exposure of the freshwater alga *Selenastrum capricornutum* to Radian Corporation's leachate 4568

Nominal concentration (% leachate)	Percentage change*							
	Chlorophyll *a*							Dry cell weight
	Day 1	Day 3	Day 5	Day 7	Day 9	Day 12	Day 14	Day 14
Growth medium control	—	—	—	—	—	—	—	—
0.1	+5	+12	+10	-1	-2	+5	+11	0
0.3	+3	-19	-13	-11	-4	-2	+16	+14
0.6	-5	-76	-68	-61	-50	-29	+21	-4
1	+3	-90	-88	-83	-74	-57	-48	-14
3	-3	-95	-95	-94	-84	-78	-74	-54
6	-5	-98	-98	-100	-100	-94	-96	-96

*Percentage change is increase or decrease of *in vivo* chlorophyll *a* in exposed cultures as compared to the control at the specified days and increase or decrease of dry cell weight at day 14.

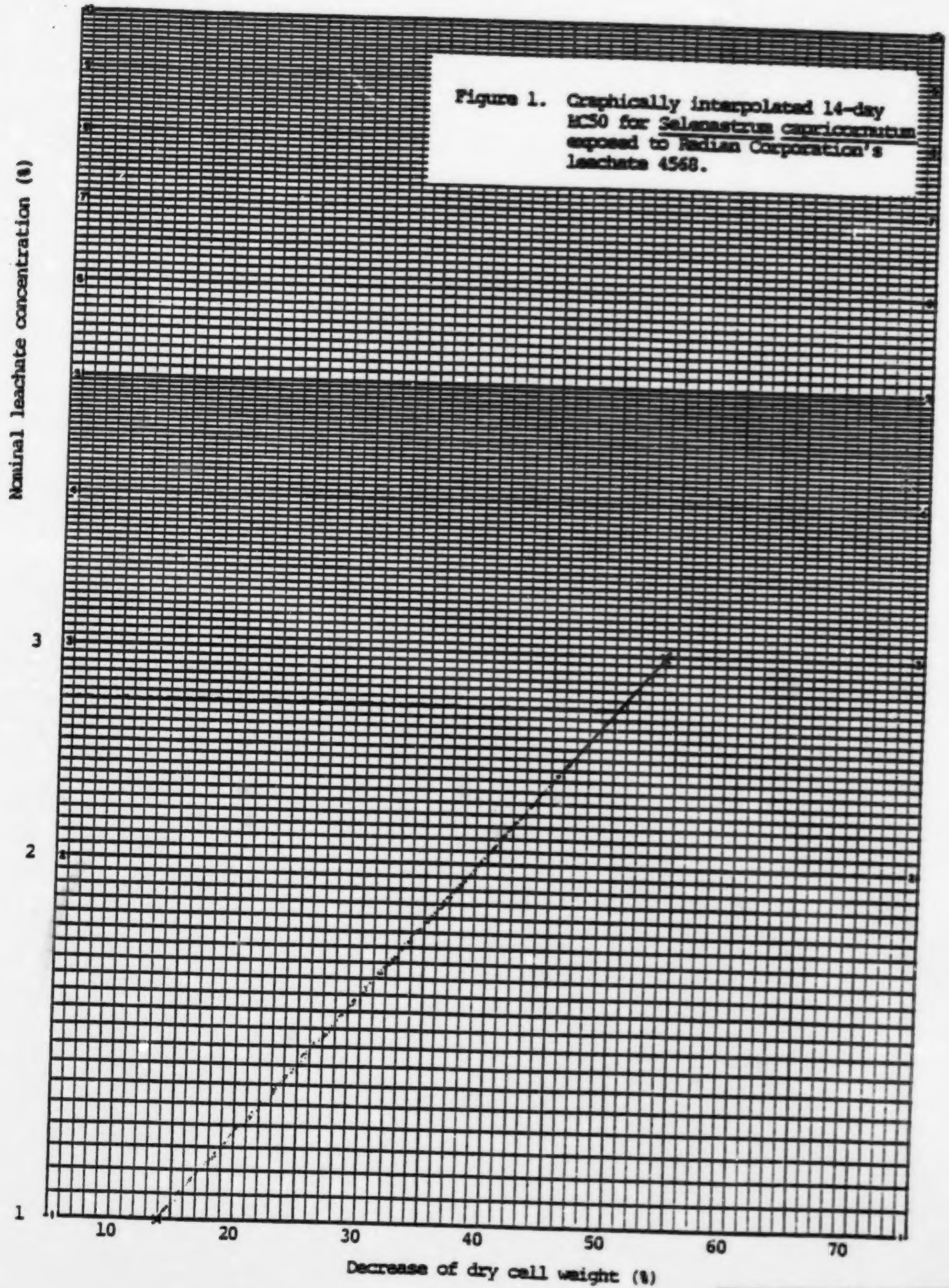


Figure 1. Graphically interpolated 14-day EC50 for *Selenastrum capricornutum* exposed to Radian Corporation's leachate 4568.

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TABLE 2. Growth constants (k) for _Selenastrum capricornutum_ exposed to Radian Corporation's leachate 4568.

Nominal concentration (% leachate)	Growth constant* (k)
Growth medium control	1.68 (0.02)
0.1	1.66 (0.05)
0.3	1.60 (0.03)
0.6	1.28**(0.07)
1	0.88**(0.12)
3	0.62**(0.10)
6	0.35**(0.09)

*Growth rates were determined from _in vivo_ chlorophyll _a_ measurements after 5 days of exposure. Values are means of measurements from three flasks. Standard deviations (±1 S.D.) are in parentheses.

**Significantly ($P<0.05$) less than the control.

TABLE 3. Results of a 14-day exposure of the freshwater alga *Selenastrum capricornutum* to Radian Corporations's leachate 4658.

Nominal concentration (% effluent)	Percentage change*							
	Chlorophyll *a*							Dry cell weight
	Day 1	Day 3	Day 5	Day 7	Day 9	Day 12	Day 14	Day 14
Growth medium control	—	—	—	—	—	—	—	—
0.1	0	0	−2	+1	−1	+3	−22	−9
0.3	+8	+7	−7	−6	−2	−4	−28	0
0.6	+24	−21	−15	0	+10	+12	−6	0
1	+3	−31	−19	−10	+12	+12	+8	−4
3	+11	−64	−58	−48	−22	−18	−23	−14
6	−5	−93	−98	−99	−92	−92	−92	−86

*Percentage change is increase or decrease *in vivo* chlorophyll *a* in exposed cultures as compared to the control at the specified days and decrease of dry cell weight at day 14.

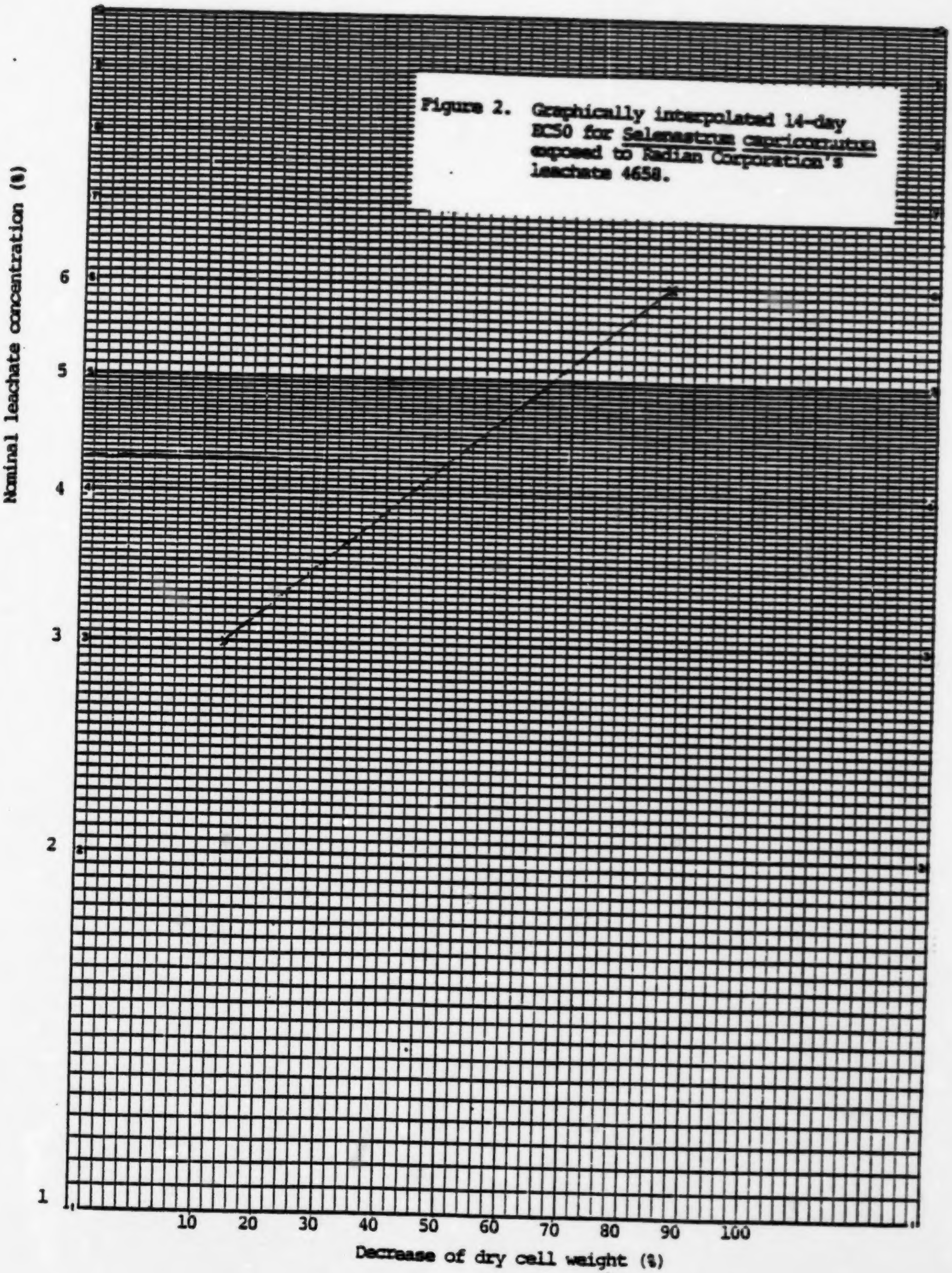

Figure 2. Graphically interpolated 14-day EC50 for *Selenastrum capricornutum* exposed to Radian Corporation's leachate 4658.

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TABLE 4. Growth constants (k) for Selenastrum capricornutum exposed to Radian Corporation's leachate 4658.

Nominal concentration (% leachate)	Growth constant* (k)
Growth medium control	1.68 (0.02)
0.1	1.67 (0.01)
0.3	1.64 (0.02)
0.6	1.54** (0.01)
1	1.59** (0.02)
3	1.32** (0.08)
6	0.30** (0.09)

*Growth rates were determined from in vivo chlorophyll a measurements after 5 days of exposure.

**Significantly ($P \leq 0.05$) less than the control.

PREPARED BY:

Terry A. Hollister

Terry A. Hollister

Study Director

AUDITED AND REVIEWED BY:

Peter Shuba, Ph.D.

Peter Shuba

Quality Assurance Unit and
Technical Coordinator

APPROVED BY:

Rod Parrish

Rod Parrish

Laboratory Director